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AUGUST 1985

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OFFICE OF DEPUTY CHIEF OF STAFF FOR LOGISTICS
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DETERMINING ECONOMIC PRODUCTION RATES

by

TRACY WORTHINGTON

AUGUST 1985

The pronouns "he," "his," and "him;" when used in this publication represent both the masculine and feminine genders unless otherwise specifically stated.

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EXECUTIVE SUMMARY

A. BACKGROUND AND PROBLEM: Each year the Deputy Chief of Staff for Research, Development and Acquisition must defend the budget submissions for its resource requirements. The budget is prepared from information supplied by the buying activities through data calls and planning documents. In responding to a recent data call, buying offices encountered considerable difficulty in determining weapon system production rates and in understanding the definitions of various production rate terms. As a result of these difficulties, the Army Procurement Research Office was tasked to investigate and resolve production rate determination and definition issues.

B. OBJECTIVE. The objective of this research was to develop clear definitions and procedures for determining various production rates.

C. APPROACH: After a review of field guidance, an investigation of past and ongoing studies provided the basis for formulation of alternative procedures and definitions. The alternative procedures and definitions were then presented to various project offices for field validation. This document reflects the alternatives which were judged to be the most beneficial for field application.

D. CONCLUSIONS AND RECOMMENDATIONS. Present definitions fall short of describing the true nature of various production rates. Alternative definitions are proposed and optional procedures for determining various production rates are described. The procedures include theoretical models, data items, production rate reviews, task order contracting, and elective scheduling. Present scheduling techniques build in large variations in production rates which could impact unit cost. Where circumstances permit, it is recommended that bid and proposal preparation instructions specify the total delivery quantity, the months in which deliveries are to be made, and a request for the offeror to propose a least cost delivery schedule.

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CHAPTER I

INTRODUCTION

A. BACKGROUND.

Each year the Deputy Chief of Staff for Research, Development and Acquisition (DCSRDA) must compile and submit a budget summary which describes the resource requirements for a future fiscal year. Before approval is granted, the budget must be defended to the approving authority. If, in the judgment of the approving authority, the budget exceeds (or falls short of) justifiable levels, directed adjustments are ordered. Implementing the directed adjustments forces DCSRDA to vary weapon system production rates to meet desired budget levels.

In late October of 1983, DCSRDA informed the U. S. Army Materiel Command (AMC) that the Economic Production Rate Working Group had agreed upon a new set of definitions for various production rates [9]. Based on these new definitions, DCSRDA requested AMC provide minimum and maximum economic production rates for 17 Army systems. AMC requested system offices provide production rates, supporting justification, and constraining component information for consideration in the FY 85 budget process. The system offices responded, and shortly thereafter AMC forwarded the requested rates. Upon receipt, DCSRDA implemented the per-unit-cost reporting of the maximum and minimum economic production rates [12].

As a result of the above data call, one system office contacted the Army Procurement Research Office (APRO) and requested a study of the determination of various production rates and related issues. Subsequent discussions between DCSRDA, AMC, and APRO revealed that many of the system

offices experienced difficulty in answering the data call. The difficulties seemed to be the result of a misunderstanding of different production rate terms, and of formulating methodologies to arrive at each production rate. It was the intent of this research to provide a mutual (DCSRDA, AMC and system office) understanding of the terms and methodologies for determining per-unit-cost production rates such that budget decisions to alter those rates will have predictable results.

B. OBJECTIVE.

The objective of this research was to develop clear definitions and procedures for determining various production rates.

C. SCOPE AND APPROACH.

This research was conducted in two parts and addressed those systems which were being prepared for initial production, or were executing a production acquisition. DCSRDA, AMC, and system offices participated in this effort. A variety of systems and secondary items was examined.

Part "A" consisted of a review of field guidance for reporting different production rates and an investigation of consumer (Army) methods for determining quantities, culminating in a set of terms and techniques for determining various production rates. Producer (Industry) strategies were also examined for meeting different production rates. The Economic Production Rate Working Group definitions (Appendix A) were used as the starting point for Part "A".

Part "B" involved validating the results of Part "A" by taking them to the system offices and critically examining the degree of realism for field application. The examination emphasized the consumer (Army) role in establishing production rates, determining the availability of necessary

data, agreeing on major influence factors, understanding the combining methodology, assuring consistent results, and itemizing the application constraints.

From these guidelines, eleven definitions (representing the most frequently used terms) were formulated. The definitions led to a literature search of theoretical models to establish past and present "state-of-the-art." Discovering that the theoretical models were basically being proposed from a "historical dollars" data base, or an examination of the man-machine workcenter concept (with emphasis on utilization), it was decided to take a systems approach; that is, view the problem as an interaction of a number of factors. The systems approach provided the techniques to examine the acquisition of both primary and secondary items in terms of consumer (the Army) and producer (industry) points of view. Although the most important point of view was the consumer, producer views were assessed to test the appropriateness of each methodology. Four alternative methodologies were selected as having the highest potential for success: data items, production rate reviews, task order contracting, and elective scheduling techniques.

D. REPORT ORGANIZATION.

The above description represents the general outline of this document. After a careful description of terms and definitions in Chapter II. Chapter III examines four theoretical models which predict expected costs resulting from rate variations. Chapter IV describes alternative methodologies which were explored as possible best solutions for determining various production rates. The last chapter summarizes the conclusions and recommendations of this research.

CHAPTER II

TERMS AND DEFINITIONS

In order to collect data, and assure common understanding, the terms used and their respective definitions were identified. Present terms and definitions described here represent financial interests within the Army. The proposed terms and definitions attempt to integrate financial, procurement, and production interests.

A. PRESENT TERMS AND DEFINITIONS.

As of this writing, there appear to be three generally accepted sources for production rate definitions: the Procurement Planning and Guidance booklet [8], the Economic Production Rate Working Group paper [9, Appendix A], and tasking documents (normally a Program Objective Memorandum, and/or Army Materiel Plan (AMP) review) [2, 10, 11, & 12].

1. PROCUREMENT PLANNING AND POLICY GUIDANCE. The booklet has six terms and definitions for describing various production rates.

> "a. Minimum Sustaining Rate: the minimum monthly rate required to produce an item on a single-shift basis, with an increase in unit cost no greater than 20% above that associated with 1-8-5 operations.
>
> b. 1-8-5 Production Rate: the maximum monthly rate of production that can be attained efficiently by each manufacturer on a single-shift, eight-hour day for a five-day workweek using installed production equipment, or what can reasonably be installed during the production leadtime.
>
> c. 2-8-5 Production Rate: The maximum monthly production rate that can be efficiently attained by each manufacturer on a two-shift, eight-hourday, five-day-work week basis, using installed production equipment, or what can be reasonably installed during the production leadtime assuming an all-out effort.

d. Maximum Production Rate with Current Tooling: for AMP purposes, this is defined as the maximum production rate that can be attained using installed production equipment (and special tooling) or that can reasonably be installed during the production leadtime, as of the date of the AMP, assuming an all-out effort.

e. Maximum Mobilization Rate: the maximum mobilization rate applies to ammunition only.

f. Maximum Production Rate: the maximum production rate applies to commodities other than ammunition."

2. ECONOMIC PRODUCTION RATE WORKING GROUP. This paper (Appendix A) has three terms and definitions for describing various levels of production.

"a. The maximum economical rate occurs just before the existing or planned plant capacity, tooling or test equipment are exceeded; i.e., further increases in quantity incur an increase in unit cost due to the inability to amortize further facilitation and rate tooling costs.

b. The minimum economical rate occurs at the knee of the curve while still making effective utilization of existing manufacturing facilities or where further reduction in quantity incurs an inordinate increase in unit cost with an unacceptable return on investment.

c. The minimum sustaining production rate allows keeping production lines open while maintaining a responsive vendor/supplier base."

3. PROGRAM OBJECTIVE MEMORANDUM/ARMY MATERIEL PLAN. Tasking documents have four terms and definitions which describe different production rates.

"a. Minimum sustaining production rate allows keeping production lines open while maintaining a responsive vendor/supplier base.

b. Minimum efficient production rate occurs at the knee of the cost/quantity curve while still making effective utilization of existing manufacturing facilities or where further reduction in quantity incurs an inordinate increase in unit cost with an unacceptable return on investment.

c. Maximum efficient production rate occurs before the existing or planning plant capacity, tooling or test equipment are exceeded where further increases would incur an increase in unit cost.

d. Maximum production rate occurs when existing tooling or test equipment are fully utilized."

When present terms and definitions are applied to systems acquisition or the procurement of secondary items, weaknesses and questions of validity begin to emerge. There appear to be at least three basic assumptions which must be true for these definitions to be credible: a producing supplier must exist, an extensive supplier data base must be available, and technical and analytical skills must be accessible. The producing supplier is necessary to provide for the collection of data dealing with 1-8-5 or 2-8-5 operations, plant capacity, effective utilization, open production lines, and responsive vendor/supplier bases. The extensive supplier data base is necessary to permit the accumulation of performance measures for future calculations. The analytical and technical skills are needed to develop cost/quantity curves, unit cost statistics, amortization schedules, and returns on investments necessary to validate the defined rate. When these basic assumptions are not true, the buying office must define and validate production rates before and during contract execution based on existing circumstances.

B. PROPOSED TERMS AND DEFINITIONS.

A careful examination of the present terms and definitions could lead one to believe that a production rate is determined after a careful analysis of producer resources. However, discussions with Army buying offices and contractors revealed that production rates are determined by the

maturity of the hardware and the nature of the competition. Methods for determining secondary item production rates were not the same as those used for systems. In dealing with secondary items, it is possible to have acceptable specifications and one or more competing producers. In dealing with systems, it is possible to have single or competing specifications and producers. Buying offices also indicated that system production rates normally increase from zero to some agreed upon level and then decrease to different plateaus with age. When discussing the subject of first delivery, both buying offices and contractors agreed that in most cases it was nothing more than a best estimate. Buying offices proposed first deliveries based on fielding strategies, or test objectives. Contractors proposed first deliveries based on projected workloads. These facts suggest a real need to adjust present definitions and add additional terms (and definitions) to further explain the necessary and sufficient conditions for a production rate. The proposed terms and definitions are:

1. Economic production rate: the number of units a consumer agrees to purchase, and a producer agrees to supply during a specified period of time, at a mutually acceptable cost.

2. Initial production: that period of time when the production rate increases from near zero to the economic production rate.

3. Leadtime: the number of workdays from contract award <u>to</u> acceptance of the first product or service.

4. Maximum efficient production rate: that production rate which maximizes inventory turnover, subcontracting, and fixed asset and workforce utilization.

5. Maximum production rate: that production rate which can be achieved from a prudent fixed asset investment.

6. Minimum efficient production rate: that production rate which minimizes inventory turnover and subcontracting, and maximizes fixed asset and workforce utilization.

7. Minimum sustaining production rate: that production rate below the minimum efficient production rate which maintains production line operations.

8. Production rate: the number of products, or services, scheduled for delivery on the last workday of a month, divided by the number of workdays in that month.

9. Terminal production: that period of time when the production rate decreases from an existing level to zero (with acceptance of the last product or service).

10. Transition production: that period of time when the production rate increases, or decreases, from one level to another.

11. Workdays: the number of calendar days from contract award <u>through</u> the acceptance of the last product or service, less all non-workdays (such as weekends, holidays, and scheduled shut-down periods).

These proposed definitions were developed to include consideration of as many basic factors as possible. They relate the timing and occurrence of unique events which are distinguished and measurable. The assumptions made in their formulation include:

a. Variations to a production rate can be accommodated by altering the number of labor hours, workforce size, number of shifts that different

departments operate, volume of subcontracting, and inventory levels.

b. The limits to which an economic production rate can be varied without encountering additional fixed asset cost range from the minimum to the maximum efficient production rates.

c. Early production contracts and their related production rates will determine the amount of required tooling and test equipment.

d. Exceeding the maximum efficient production rate will normally require additional assembly tooling, test equipment, labor hours, and may require more facilities.

The remainder of this document will use the proposed terms within the context of their stated definitions.

CHAPTER III

PRODUCTION RATE MODELS

Several models have been proposed for estimating the effect of production rate changes on unit costs. In this chapter four models are discussed which are identified by the names of their proposers. Much of the material in this chapter is taken from an earlier study [18]. Also, a more complete review of production rate research can be found there.

A. C. H. Smith [18 and 19].

C. H. Smith's model is based largely on the premise that fixed overhead is the primary explainer of cost-rate effects. Smith concluded that the effect of inefficiencies in the use of direct labor and materials is generally smaller over limited changes in production rates. These inefficiency effects were also much more unpredictable from an outside point of view. Asher [3] in 1956 reported evidence in the airframe industry of a consistent and appreciable rate effect only on the overhead cost element. Large et al [4], found further supporting evidence in airframes. Such findings were also supported by missile system cases. McIntyre [17] described the effect of adding learning curve cost behavior to linear cost-volume-profit analysis. This is the main idea of the model recommended here. The model is also quite similar to the Linder-Wilbourn [16] model (discussed later) but requires fewer estimates.

Beginning with production planning of a system prior to the start of actual production, a total quantity of Q units will be bought. What is the estimated cost per unit if the system is procured uniformly over T_1 years? What if it is procured uniformly over T_2 years?

The variable costs y for xth unit are given by:

$$y = ax^{-b}, \ a \ \& \ b > 0,$$

where a is the first unit cost, and b is the slope of the cost improvement curve. If the acquisition period is T_1 years, then the annual production rate is Q/T_1. The annual fixed costs allocable to the program are constant and denoted by F. Then the cost of production in year one is given by the following equation:

$$C(1) = \left(\sum_{k=1}^{Q/T_1} a x_k^{-b}\right) + F.$$

In general, the cost of production in year n is given by

$$C(n) = \left(\sum_{k=\frac{(n-1)Q}{T_1}+1}^{nQ/T_1} a x_k^{-b}\right) + F.$$

Then the average cost per unit in year n is given by

$$\frac{C(n)}{Q/T_1} = \frac{T_1 \, C(n)}{Q}$$

The total cost (TC) of the system is approximated by

$$\frac{\int_0^Q ax^{-b}\,dx + T_1 F}{Q} = \frac{(a/(1-b))\,Q^{1-b} + T_1 F}{Q}$$

This model is useful for estimating the average unit cost differences for procuring the same total quantity under different rates. An accurate cost projection depends on a reasonably constant annual fixed cost allocable to the program and on the ability to reasonably estimate this fixed

cost. It is easy to modify the model to accommodate fixed costs that change from year to year provided these can be estimated. Likewise a slight modification is required to deal with those cases where substantial production experience is acquired for units not sold to the analyzing buyer (e.g., Foreign Military Sales). Discount factors can also be incorporated as needed. C. H. Smith [19] provides illustrative examples of the use of this model.

B. Linder and Wilbourn [16].

Linder and Wilbourn presented a theoretical model analyzing the effect of production rate on recurring missile costs. They assumed that the production facilities are fixed. Their modeling was based on an analysis of the behavior of direct and indirect costs under a rate change. They reasoned that a higher rate reduces the direct fixed cost per unit. Further, a higher production rate would lead to a smaller percentage increase in indirect costs than in direct costs. Therefore, they reasoned, a lower overhead rate should be applied to direct costs. Both of these factors work toward lower unit costs when a higher rate exists. Therefore, Linder and Wilbourn concluded, that all else being equal, the cost improvement curve for high rate would lie below that for low rate.

The researchers then questioned the impact of a rate change on the cost improvement curve slope. They suggested the two factors below.

1. Variable direct costs become a larger portion of total direct costs at higher rates.

2. Indirect costs are reduced at a lower rate as direct costs fall. The net effect on the slope depends on the relative amounts of direct and indirect costs per unit and the proportion of each regarded as fixed or

variable. Linder and Wilbourn assumed that the effects of wage mix and materials are of secondary importance and supportive of the principal effects described. These areas were therefore not treated in the model.

In their first of two models, Linder and Wilbourn represented the unit recurring cost URC_i as a product of direct costs and an indirect factor. The significant terms were defined as follows:

ax_i^b = variable direct cost of unit i,

R = annual production rate,

$\frac{k_3}{R} + k_4$ = "semi-fixed" unit direct cost,

B = total direct charges on other business,

and a, b, k_1, k_2, k_3, k_4 are constants.

Then the recurring cost equation is

$$URC_i = (ax_i^b + k_3/R + k_4)\ [k_1/(aRx_i^b + k_3 + k_4\ R+B) + k_2 + 1].$$

Linder and Wilbourn applied their model using a set of parameter values felt to be typical for a missile program. They found a relatively small rate effect. For their parameters a doubling of the rate from 500 to 1000 per year reduced the cost of the 1000th unit by 5.6%.

The model described above assumed a constant production rate throughout the year. This means that adjustments for increased efficiency due to learning are made by reducing the level of resources used during the year. Thus, the model ignored the costs of moves such as reducing employment. Linder and Wilbourn proposed a second model which assumed production is scheduled over a year in a way that keeps the rate of resource use constant. In this approach the instantaneous production rate constantly changes. This model is given by the following equation:

$$URC_i = ax_i^b \left(1 + \frac{k_3 + Lk_4}{\sum_i ax_i^b}\right) \left(\frac{k_1}{\sum_i ax_i^b + k_3 + Lk_4 + B} + k_2 + 1\right),$$

where L is the lot size (corresponds to R in the earlier model). Linder and Wilbourn reported that the first model was easier to use and was often a useful approximation of the second.

Linder and Wilbourn reached several conclusions from analysis of their models. First, they concluded doubling the production rate lowered the average unit cost about 3-7% for the range of rates and quantities they examined. They reported this difference tended to be greater for larger cumulative quantities. Further, they concluded that rate changes had only a slight effect on the unit cost improvement curve slope. Finally, they found that the observed effects were relatively insensitive to changes in most of the parameter values. In fact one can observe from their sensitivity analysis that variations in the learning curve slope have by far the greatest impact on costs. The only other parameter that shows appreciable sensitivity in the regions they tested is B, the total direct charges on other business.

Linder and Wilbourn focused their paper and their example on a hypothetical missile program. The model itself, however, is independent of program type. To apply the model one needs to be able to estimate cost behavior via the parameters described earlier. These parameters are not specific to any special type program. Their estimation requires an understanding of the rate responsiveness of individual cost categories such as "semi-fixed" direct costs.

Possible shortcomings in the model are now described. First, the rate effect is independent of the current rate position relative to an optimal or standard rate. The model does not permit incorporating any breaks in the cost functions. These breaks could exist at rates for which a major change in the production process occurred (such as another shift). They assume the facilities are fixed, and yet cost savings accrue for all rate increases without limit. The Linder and Wilbourn model also does not deal with the issue of discounting costs.

C. L. L. Smith [20] and Bemis [5].

L. L. Smith in his doctoral dissertation analyzed three programs for which a larger number of data values were available due to long production periods. He fitted a regression model to the data for each case using measures of rate and direct labor hours. His model had the form:

$$Y_i = B_0 (X_{1i})^{B_1} (X_{2i})^{B_2} \text{ where}$$

Y_i = the unit average direct labor hours required per pound of airframe in lot i

X_{1i} = measure of cumulative production which is one-half the i^{th} lot size plus the total production of all prior lots

X_{2i} = the lot i production rate

and B_0, B_1, and B_2 are the model parameters to be determined by a least-squares fit. Smith applied the regression to the F-4, F-102 and KC-135A programs. Where the data permitted, he applied the model separately to fabrication and assembly labor hours. Smith compared the model above with a reduced model which did not contain the production rate term. The rate term was found to be an important contributor to the explanatory values for cases with similar production quantities and rates. Therefore, Smith

did not believe any process averaging parameter values across programs would create a reliable general cost model. He noted the wide variation in parameter values for cases with similar production quantities and rates. In the case of the F-4, the predictive ability was greatly enhanced by using the rate term. For test purposes Smith used limited parts of the data bases to predict future labor hours. While, for example, the reduced model might have a 12-15% prediction error, the full model might be only 2-3% in error. The predictive ability of the other two programs was not so convincing; however, it improved by use of the full model.

Recent masters theses by Air Force Institute of Technology students have applied and evaluated Smith's model on other programs. One thesis applied the model to avionics programs, and one to aircraft engines. These works and the programs covered are identified below:

(1) Congleton and Kinton (6): T38/F-5

(2) Stevens and Thomerson (21): ARC-164 radio, Computer Data Converter

(3) Crozier and McGann (7): J-79 engines , TF-41, F-100.

The above theses tend to support the conclusions of Smith. Estimates for some programs, however, benefit much more than others from adding the production rate terms.

The Smith model is a logical tool to use when a lengthy production history for a given program is available. Use of the model is, of course, limited to the particular program to which the regression equation is applied. The approach offers no general help for the problem of understanding rate effects prior to actually experiencing a lengthy production history with a wide range of rates. Moreover, estimating the effect of

rate on direct labor hours may leave one far short of understanding the effect on unit cost. This result arises from the fact that wage related costs are affected by rate changes due to factors such as shift premiums and overtime.

Bemis [5] took the L. L. Smith approach but used the dependent variable in the regression model to actually predict unit costs rather than labor hours.

D. Balut [4].

Balut's model was designed to assist the Office of the Secretary of Defense in estimating the cost effect of program rate changes as part of the development and review of the Five Year Defense Plan. His model also focuses on the fixed overhead forms by the program. The first step in applying the model is the calculation of cost using a standard learning curve function. Then an adjustment for rates is made according to the following relationship:

$$F_i = PR\left(\frac{Q_i^{OLD}}{Q_i^{NEW}}\right)^b + (1 - PR)$$

where

i = lot number

F_i = the factor used to adjust the estimate for lot i that was derived from standard learning curve considerations

Q_i^{Old} = the quantity in lot i in the basic service program

Q_i^{New} = the new quantity for lot i

P = fraction of price due to overhead

R = fraction of overhead fixed in the short-term

b = a regression parameter

Balut applies his model to aircraft, but it should be more widely applicable if appropriate values of PR and the exponent b can be determined based on available data.

E. <u>EVALUATION</u>.

An evaluation of these four models suggests a need for greater consideration of the issues raised by Lawrence and Zanakis [15]. That is, it would appear that minimum thought has been devoted to such variables as workforce size, overtime and undertime, backlogs and inventories, and outside contracting. Also, most learning curve effects are experienced during initial production when established time standards are a goal. Once time standards are reached, the measurement of learning effects cannot be accurately measured. In addition, the search for historical cost statistics, which are composed of the desired elements, can be difficult to match by "similar" program or contractor. Although these factors together degrade the integrity of model results, the models themselves can be applied under the appropriate conditions with a high degree of confidence. The methods explored in the next chpter offer some alternative solutions.

CHAPTER IV

ALTERNATIVE METHODOLOGIES

After attempting to apply the models of the previous chapter to the data call requirements for the participating project offices, APRO discovered two major problems. The values of some variables were difficult to determine, and the models did not appear to fit the particular situations. The situations ranged from early initial production to development of modified production hardware. Therefore, other means had to be developed to answer current and future data call requirements. Data items, Production Rate Reviews, task order contracting, and elective scheduling techniques were found to be some of the better alternatives for determining economic production rates, different levels of production, and values for model variables. The delivery schedule derivation (Appendix D) employed in the task order contracts, the Production Rate Review, and the elective scheduling technique were products of this research.

A. DATA ITEMS.

To determine production rates in conjunction with ongoing contracting efforts, data items represent one of the least expensive methods available. A data item is a contract device to collect information from a contractor (DFARS 27.410-6). However, the decision to use data items must be made during the preparation of the statement of work. When the decision to use a data item is made, a second decision to use an available or unique data item must also be made.

Of the available thirty-eight data items dealing with the subject

of production, four address the concept of a production plan. Two of the four data items are product-unique. Of the two remaining data items (DI-P-3460 and DI-P-1612), only one requires the producer to document any variation of the contracted delivery schedule.

Data item DI-P-1612 has sixteen subjects to be documented in the specified production plan. Two of the subjects are Production Delivery Capability and Alternate Production Delivery Schedules. Production Delivery Capability requires a contractor to "...delineate the lowest and highest delivery rates which are sustainable for a minimum of one year." Alternative Production Delivery Schedules require a contractor to "... delineate the slowest, fastest, and most economical (lowest cost to the Government) monthly delivery schedules from contract award thru final delivery."

Discussions with a project officer who had placed DI-P-1612 on contract revealed a less than favorable contractor response. The contractor failed to meet the requirements set forth in the data item. In context, the contractor stated in his production plan under the above named sections that he was unable to determine the required production rates. Careful analysis of the contractor's maturity with the system showed:

1. the contractor had produced ten production units when the data item was placed on contract,

2. the data item does not provide for consideration of production rate movement from an existing capability to a higher or lower capability, and

3. the data item constrains the contractor to define these rates in terms of existing resources (suggesting gross contractor inefficiencies or only lower rates are possible).

These conclusions could make one believe that the requirements were unrealistic and could not be honestly answered.

A second project office, which had placed DI-P-3460 on contract, used the statement of work to explore variations in production rate. In addition to full rate (100%) production, the production plan was to address 60 and 40 per cent delivery rates. Also, a sensitivity analysis was to be accomplished through a range of 15% above and 15% below each production level (i.e., 100% $\pm$15%, 60% $\pm$ 15%, and 40% $\pm$ 15%). The results of this effort are not yet available, but it does appears to have been applied too early since this was a full scale development contract.

As an alternative to available data items, unique data items offer a desirable, but long-term, solution to the production rate problem. The unique data item can be prepared to meet the special conditions of the procurement and is free of the burdens of listing various related facts and equipment. The two major disadvantages are (1) securing approval for use, and (2) being able to carefully word the requirements such that they are realistic and not beyond system maturity.

Unique and standard data items are relatively inexpensive and can provide useful, as well as undesirable, results. They provide for the collection of data on current production operations, and they can force a contractor to analyze production activities to meet present and future requirements. Standard data items appear to produce less than desired responses when they are applied at an inappropriate time. Except for product-unique data items, vocabularies used to describe information requirements are usually "text-book" and general; this usage often

misleads the respondent. A more detailed study of the correlation between data item results and the requirements vocabulary might prove to be most enlightening.

B. PRODUCTION RATE REVIEW.

The Production Rate Review was an alternative developed for determining various production rates. The thrust of this approach is to send a small group of government specialists to the contractor's final assembly facility and conduct an investigation of his operations. The government group would be managed by a director and divided into three small teams (Production Processes, Contracts and Agreements, and Business and Financial). Each team would conduct a separate subject-area investigation. The Production Rate Review concept was formulated on the basis of an accelerated three day visit as outlined in Appendix B. The underlying objective of this investigation is to collect information and data in sufficient detail to permit calculation of desired production rates.

After the introductions and presentations of the Entry Brief, the director would request a plant tour. During the tour, team members would direct their attention toward the administration and control of the contractor's production operations. Of particular interest to the Production Processes team would be identification of primary assemblies (those assemblies that provide the "back-bone" to which other detail parts and subassemblies are added), the general flow of materials, locations of subassembly and final assembly operations, and contractor techniques for maintaining status and location data on each production lot. The Contracts and Agreements team members would be alert for the functional support

supplied by the contractor's Purchasing, Subcontracting, and Industrial Relations departments. The Business and Financial team would concentrate on accounting, finance, and marketing functions. At the end of the tour, each team would independently begin to collect specific performance statistics based on a conceptual production operations model shown in Figure 4-1.

The Production Processes team would begin its detail investigation with the shipping function and work backwards toward the fabrication function as shown in Figure 4-1. In each functional area, the team would formulate and define time standards, number of parallel processors, and other data necessary for rate calculations.

The Contracts and Agreements team would begin its detail investigation with the purchasing functions. The objective of these examinations would be to sample and develop a distribution of time standards for the flow of standard items and (subcontracted) products into the output of the production process. These time standards would have to include: quantity determination, order placement, leadtimes, vendor fabrication, delivery time, receiving inspection, and transportation to the assembly point. With completion of the purchasing and subcontracting functions (at the end of the second day), the remainder of the review would be devoted to collecting statistics and data on the labor force and related labor-management agreements.

The Financial and Business team would begin its investigation with an analysis of the accounting function. Within the accounting function, percentages of competing sales would have to be determined, as well as a breakdown of operating expenses for the project office product. Interviews

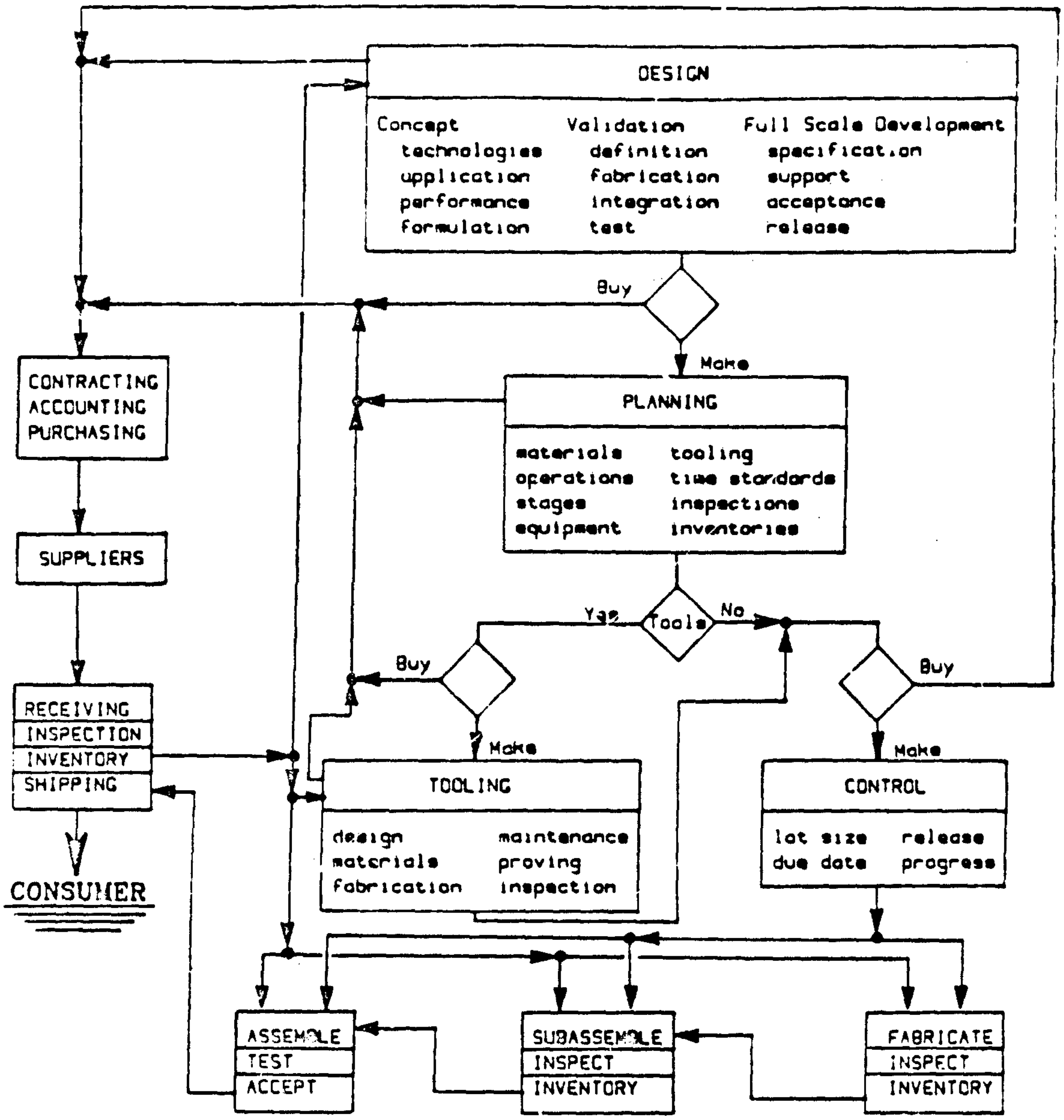

FIGURE 4-1: CONCEPTUAL PRODUCTION OPERATIONS MODEL

and discussions with the financial and marketing functions would also have to be conducted to accumulate an information base from which advanced planning could be projected.

With the completion of the Production Rate Review, required production rates could be determined. This information could also serve as the basis for simulation models to analyze sensitivity and variability characteristics of contractor processes. A Production Operations simulation could be constructed from information and time standards collected by the Production Rate Review team.

A review of this nature was recently executed by AMC and a project office. Their experience has shown that such a review required approximately 75 man-days to complete. Seventeen people collected data for about two and one-half weeks and fourteen people reduced the data over an additional two and one-half week period. The results provided a minimum sustaining production rate and an expected per unit cost.

A Production Rate Review was proposed to a project office as a solution for determining an economic production rate. Because the idea of varying production rates had not been a major consideration (beyond data item level) in earlier project office statement of work preparation, and it would take approximately two years to integrate a Production Rate Review requirement into the next contract buy, any current effort would be an over and above cost to the present contract. The project office was just completing its first initial production contract and project officials could not justify the additional cost. Early planning decisions and cost versus worth of collected data led to the decision to seek out other

alternatives.

C. TASK ORDER CONTRACTING.

To determine economic production rates independent of ongoing efforts, the task order contract offers one of the best solutions. The task order contract provides the means for the preparer to carefully define controlled conditions, collect cost data on different production rates, and forecast intermediate production rate costs. This alternative was proposed and favorably received by a project office. Working with the project office, APRO developed a statement of work to measure the cost effects of different scheduling techniques and rates of production. The statement of work was submitted through the project office to the contractor with a request for bid.

1. Statement of Work. Two statements of work were prepared (Appendix C). In general, the statements of work tasked the contractor to conduct a cost analysis and prepare cost estimates for producing missiles based on five predetermined delivery schedules, each of which had been divided into six different purchases. After determining the cost estimates, the contractor was tasked to analyze the delivery schedules and rearrange the monthly deliveries to exhibit the best delivery schedule. The third task required the contractor to prepare cost estimates for each purchase of the five proposed delivery schedules.

The difference between the two statements of work centered around the level of detail in describing the cost estimates. One statement of work (Appendix C, page C-7) required one estimate for each purchase of each delivery schedule. The second statement of work required that each cost

estimate be broken down into six factors - direct labor (less overtime), overtime, material (less subcontracting and inventory), subcontracting, inventory (or holding), and overhead.

2. Predetermined Delivery Schedules. In formulating the delivery schedules, it was observed that calendar years repeat themselves exactly every twenty-eight years (see Appendix D, Table D-2). It was also observed that the number of non-weekend days in any month was determined by the number of calendar days and the week day of the first day (Table 4-1). Noting that the number of non-weekend days varied

TABLE 4-1: Non-Weekend Days Per Month

MONTH LENGTH		WEEK DAY OF 1st						
		Su	Mo	Tu	We	Th	Fr	Sa
CALENDAR DAYS	28	20	20	20	20	20	20	20
	29	20	21	21	21	21	21	20
	30	21	22	22	22	22	21	20
	31	22	23	23	23	22	21	21

from 20 to 23 days, some means had to be developed to reduce the nonweekend days to work days.

Based on a telephone survey of five government contractors, holidays and scheduled shut-down periods totaled from nine to 22 nonweekend days per calendar year. Two contractors had a scheduled ten day (non-weekend) shut-down period each year. One contractor had seven holidays and two

others had twelve. Based on these results, it was decided that actual work days for any contractor had to be determined by an inquiry of that contractor.

After securing the holiday/shut-down schedule from the participating contractor, an analysis was made of the project office planned delivery schedule. Production rates for the last purchase and the next two purchases were plotted in Figure 4-2 for analysis. The analysis showed that the average daily production rate for the last buy was 10.6 units, the next buy was to have a 21.9 average daily production rate, and the second buy would have a 20.2 average daily production rate. The jump from 10.6 to 21.9 and the variation of monthly average daily production rates appeared excessive and could result in higher costs. It was then decided to develop unique delivery schedules for this effort.

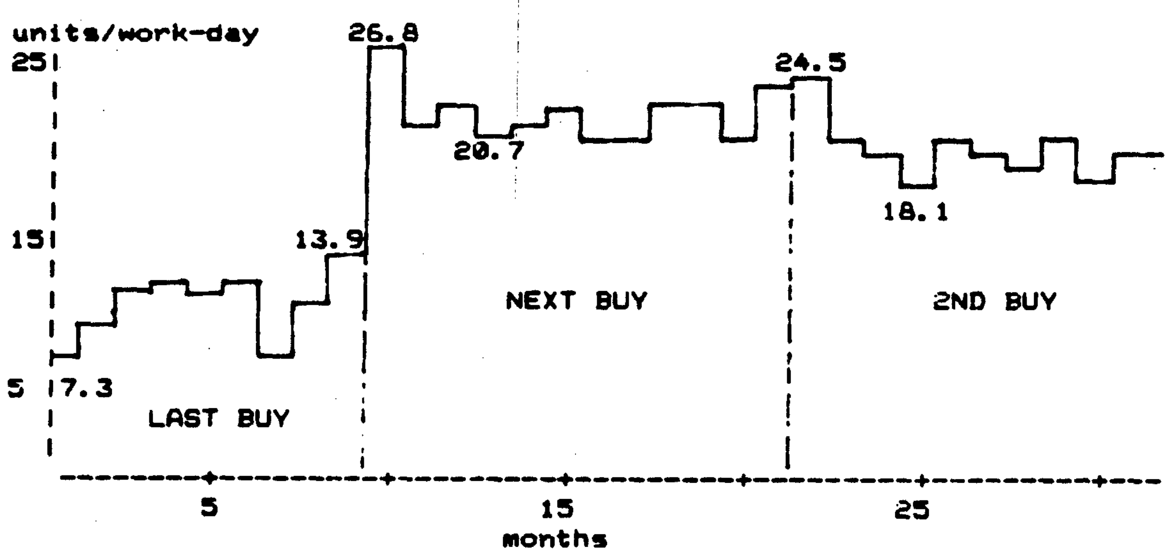

FIGURE 4-2: Project Office Planned Production Rates

The project office had formulated deployment levels, the total purchase quantity and the duration of the procurement. The project office had 30,026 missiles to procure during the next 71 months, and the 71 months was to be broken up into six individual contracted buys.

From these guidelines, APRO developed five different delivery schedules. The Schedules were entitled "Total," "75 Per Cent," "Cut-Back," "25 Per Cent" and "Minimum." The "Total" delivery schedule represented a procurement of 30,026 missiles during a 71 months period which would be achieved through six contracted buys. The "75 Per Cent" delivery schedule represented a procurement of 22,520 missiles. The "Cut-Back" delivery represented a production rate with an imaginary future funding reduction. A 7,506 missile procurement was proposed as the "25 Per Cent" delivery schedule. The minimum production rate was arbitrarily set at two missiles per work day as the "Minimum" delivery schedule. Each schedule employed a transition period to move the contractor's past production capability to a new production rate. Learning curve and "ramp" transition production rates were evaluated, and the "ramp" method was selected (see Appendix D for calculation techniques). The "Cut-Back" schedule transitioned to a steady-state production rate for two buys and then transitioned to a lower steady-state production rate for the last two buys.

To examine the cost effects of variation in monthly average daily production rates, five scheduling techniques were employed. They were called "Project Management Office (PMO)," "Government (GT)," "Contractor (XR)," "Five Per Cent (5%)," and "Fifteen Per Cent (15%)." The assumption that there were 21 work days in every calendar month was the basis for PMO

scheduling. Reducing the monthly non-weekend days by the number of Federal holidays determined GT scheduling. Scheduling based on the contractor's actual work days are labeled XR in Figure 4-3. Scheduling based on the contractor's actual work days with an induced variation of plus and minus five per cent was used for 5% scheduling. The same basis as 5% scheduling, except the induced variation was plus and minus fifteen per cent was used for 15% scheduling. Uniform rate increases and decreases were used for all scheduling techniques. The predetermined production rates and scheduling techniques are shown in Figure 4-3. The "spikes" near the beginning of GT and PMO scheduling were caused by a fifteen-day contractor shut-down period.

Submitting the statements of work to the contractor with an invitation for bid proved to be not cost effective. However, an examination of the timing (the contractor was in the early stages of initial production) revealed that task ordering methods could be best applied later in a later production phase.

D. ELECTIVE SCHEDULING.

When examining the participating project office's delivery schedule (Figure 4-2), a question was raised concerning the scheduling practices employed by other project and buying offices. Were other buying activities "building in" large production rate variations resulting from similar scheduling practices, variations which could force the contractor into higher cost operations (such as overtime, additional shifts, or conversely idle capacity, lay-offs, etc.) for varying lengths of time? These variations could result in the contractor passing along those high costs

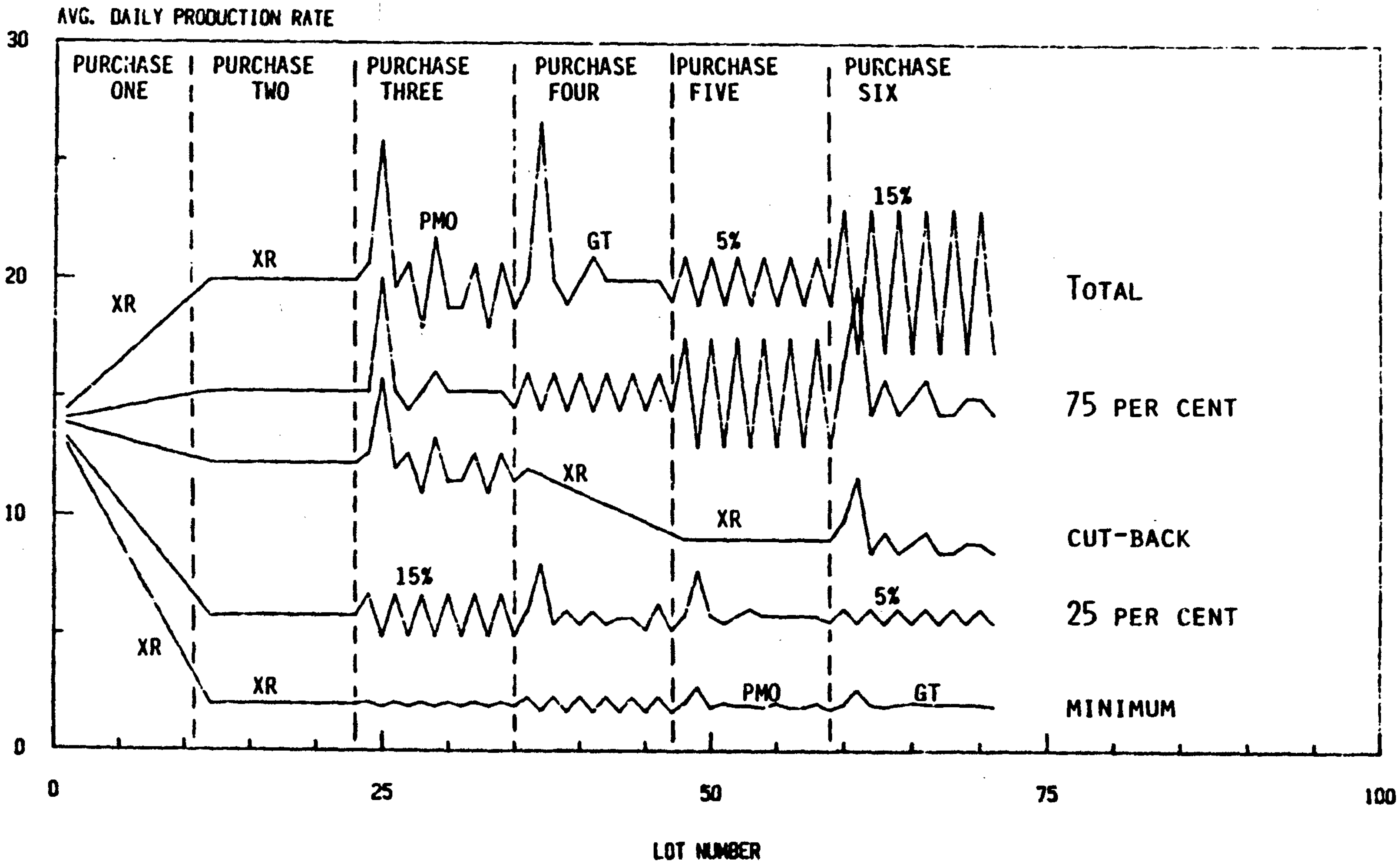

FIGURE 4-3: PREDETERMINED PRODUCTION RATES

to the government. These questions suggested APRO should conduct a survey of the results of other project and buying office scheduling practices.

The survey was to determine if the same scheduling practices were being used by other buying activities. Six product delivery schedules were examined from different buying commands. Systems and secondary items were examined. Average daily production rate varied from as low as 2.8 to as high as 624.0 units. The results of the survey are shown in Figure 4-4.

Variations in production rates were very high (Figure 4-4). Secondary items seem to have smaller variations, but the larger quantities suggest machine intensive operations, and hence greater contractor difficulty in meeting the changing rates. The only possible recourse for the contractor appears to be "rate leveling" (produce equal numbers, with some deliveries late and some early), or "advance production" (producing all units and shipping on schedule). Both of these methods are risky, and under certain conditions, one could be considered illegal. The project systems have significant variations in production rate. Some of this variation can be explained. The two largest variations (2785.9% and 1356.8%) are based on annual production rates. This fact does not really alter the increased workload that was placed on the contractor, or the fact that the contractor agreed to meet these requirements. The system contractor seems to be faced with the same problems as the secondary item producer, and can respond to the problem in much the same way.

This problem has been recognized by the Congress, and included in the FY 1985 Defense Appropriations Act was a clause which directed buying offices to provide the offeror an opportunity to propose quantities which

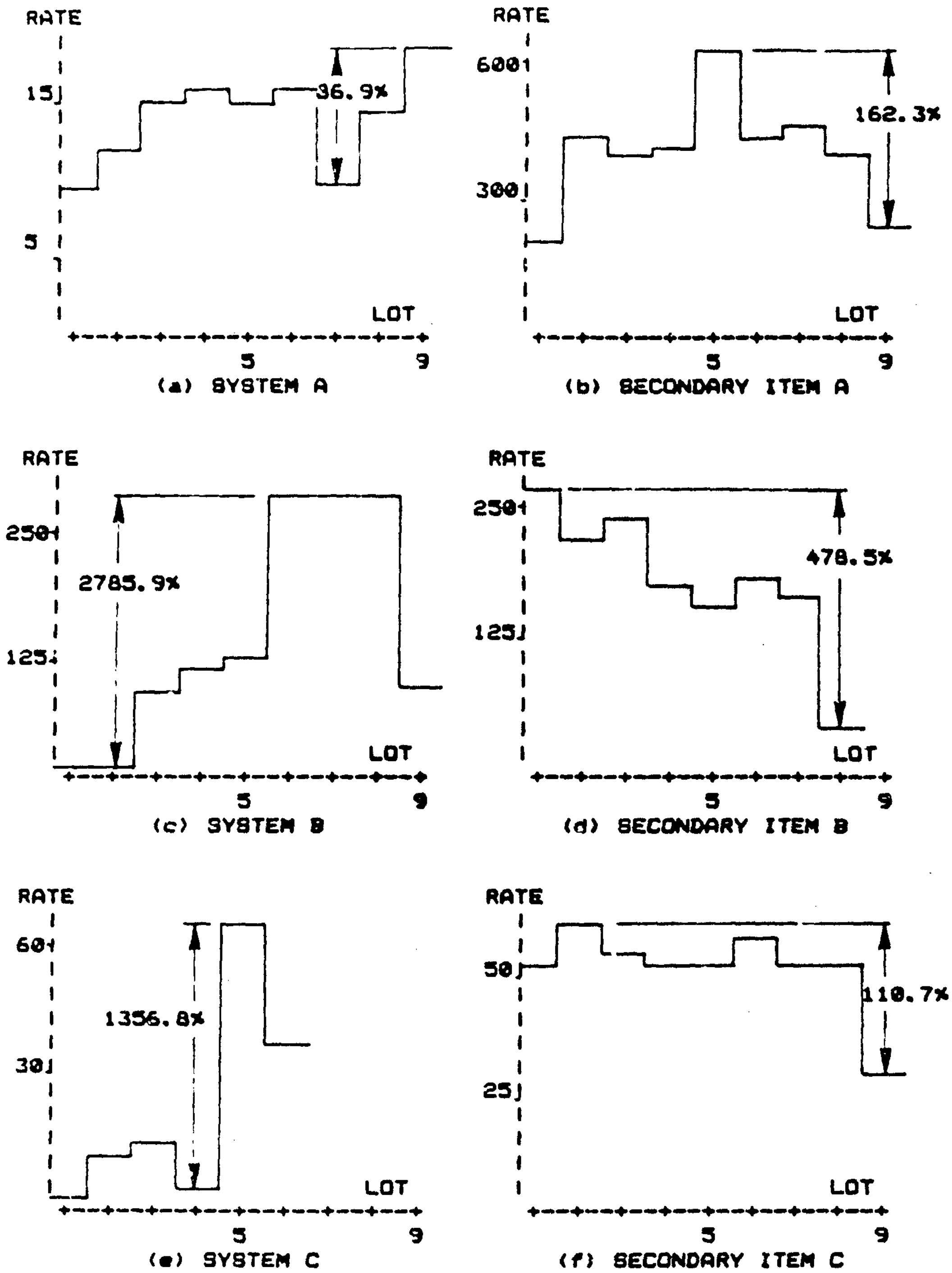

FIGURE 4-4: Survey of Production Rate Variations

would be more economical to the government. However, careful examination of this option suggests that it is not necessarily a solution. From the potential producer's point of view, what is the incentive? If the offeror does not meet all of the bid (or proposal) preparation instructions to the letter, the buying office could judge the submission non-responsive. To propose an alternative delivery schedule suggests returning to the original facts and figures and sorting out opportunities for cost reduction. The result is a second proposal at a reduced cost to the government, reduced contractor sales dollars and reduced contractor profits. Again, beyond a competitive cost position and fear of disqualification from the potential producer's point of view, what is the incentive?

There is an alternative which would enhance the competitive process and reduce the variations in production rate (which could conceivably reduce costs). The bid or proposal preparation instructions can specify the delivery quantity and the period of time in which deliveries would be made. The offerors can be instructed to propose a least cost delivery schedule that is within the specified time period and includes the total quantity.

This elective scheduling procedure would relieve the buying office from placing unrealistic production requirements on a contractor, and provide the contractor with the opportunity of matching his known operational capability to that of the buying office. It would also seem reasonable to expect a higher probability of successfully meeting the final contract delivery objectives. However, the government would still be responsible for establishing the purchase quantity and the delivery time

period, but it would not have to define specific quantities for each month. The procedure is very simple and could be applied to many secondary items, as well as initial production for major systems, and it could even be used in sole source procurements.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Determining economic production rates and possible variations is an art and a science that demands considerable study. The concentration of this study has been upon the definitions, models and methodologies of determining production rates. The conclusions and recommendations of this study are based on guidance documents, discussions with government and industry officials, and an analytical investigation of contracting and management alternatives.

Present definitions appear to be an outgrowth of an understanding of contractor operations. They relate to efficiency and capacity of installed production equipment and special tooling when operated on one or two shifts, eight hours a day, and within five-day work-weeks. With the introduction of new DCSRDA definitions, there is an attempt to establish a relationship between production rate and cost. From the research of this study, there seems to be a cost to establish a production rate, and a cost to maintain a production rate. The cost of establishing a production rate includes preparing the design for production release, planning the production operations, determining the required tooling, buying the materials to construct the tooling and products, arranging the facilities, and balancing the operations through the initial production period until the desired rate is achieved. The cost of maintaining a production rate includes the materials, labor, and overhead costs that are necessary to sustain steady-state production operations. Once the desired rate (sometimes called the economic

production rate) has been reached, it is possible that by changing the volume of contracting out, the amount of overtime, the number of shifts, and the workforce size, one can increase or decrease the production rate within some limits. What these limits are, and what are the costs associated with them are the questions DCSRDA is asking the buying offices. The present definitions by themselves do not convey this message; however, the proposed definitions presented here describe the true nature of production rates. These proposed definitions should be adopted and published in current planning and guidance documents.

There are many theoretical models which can be useful in computing cost estimates of changes in production rates. Most of these models require some type of data base to support the calculations. The data bases must normally contain measures of a contractor's operations or some characteristics of the product being produced. These measures are often overhead, fixed costs, direct and indirect labor, and pounds of product. More often than not, it is also desirable to have the contractor's "learning" rate or slope to permit production cost calculations. The strength of these models is their ability to forecast costs of known products having accessible data bases.

To collect the data for model calculations or to answer DCSRDA data calls, four major methodologies are available - data items, production rate reviews, task order contracting, and elective scheduling techniques. Data items are inexpensive, but must be carefully applied such that mutually (Army and contractor) understood information will be supplied. The production rate review is fast and would appear to be most accurate, but should

be integrated into the contract's statement of work for cost control. Task order contracting provides the greatest independence, versatility, and control for determining the cost of production rate variations. Elective scheduling offers the highest potential savings for the Army. When contracting conditions permit, bid and proposal instructions could specify the total delivery quantity and the months in which deliveries are to be made. The offerors would then propose a least cost delivery schedule. Elective scheduling techniques should be tested for both major systems and secondary items.

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APPENDIX A

ECONOMIC PRODUCTION RATE

WORKING GROUP PAPER

ECONOMICAL PRODUCTION RATES - DEFINITION

An economical production rate is one which makes effective and efficient utilization of existing manufacturing plant and facilities. Generally speaking, the higher the rate, the lower the unit production cost. Higher rates enable industrial producers to: (1) spread fixed costs, especially overhead items, over larger numbers of units and/or (2) use more efficient production techniques and processes that are economically viable only at higher production rates and under the expectation of stable predictable business continuing at high rates in the future.

Economical production rates can be plotted by deriving unit cost versus quantity curves as depicted in Figure 1. The planned or programed production rate for a given commodity should fall in the economical range between points 1 and 2; as close to point 1 as is affordable but no lower than point 2.

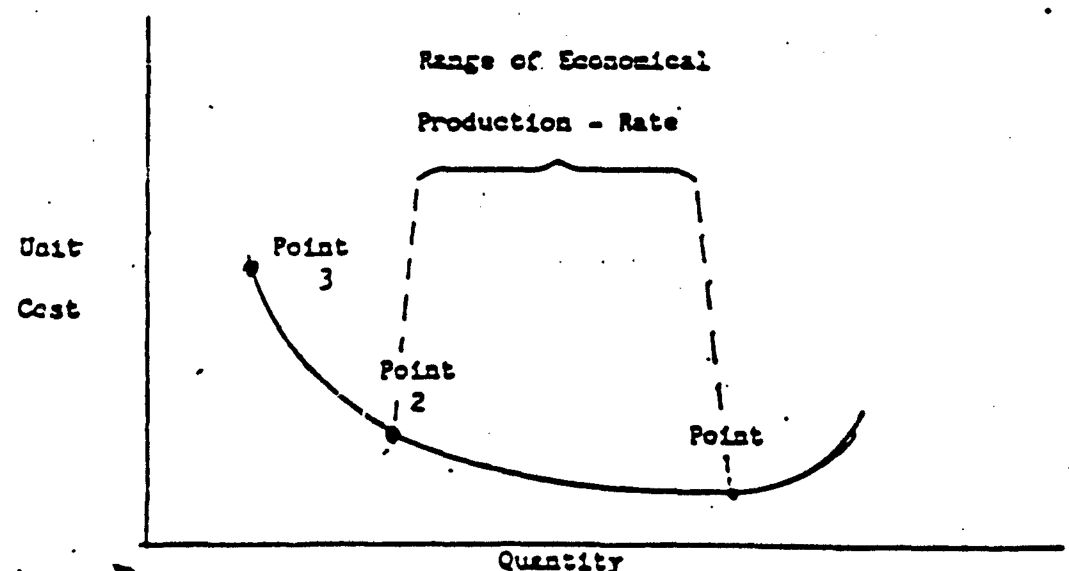


FIGURE 1

At the upper end of the unit cost versus quantity curve, occurs the maximum economical production rate, point 1. Next below is the minimum economical production rate, point 2. At the lower end of the curve, occurs the minimum sustaining rate, point 3. These points are further defined as follows:

Point 1. The maximum economical rate occurs just before the existing or planned plant capacity, tooling or test equipment are exceeded; i.e., further increase in quantity incurs an increase in unit cost due to the inability to amortize further facilization and rate tooling costs.

Point 2. The minimum economical rate occurs at the knee of the curve while still making effective utilization of existing manufacturing facilities or where further reduction in quantity incurs an inordinate increase in unit cost with an unacceptable return on investment.

Point 3. The minimum sustaining production rate allows keeping production lines open while maintaining a responsive vendor/supplier base. This rate can frequently be equated to maintaining a warm production base. The minimum sustaining rate is <u>not</u> the minimum economical production rate and should be used sparingly on a short term basis until an economical production rate can be restored.

An economical rate for many commodities is one at which the facility is operating nominally on a one-shift basis, however, programs can be structured to accommodate different bases (such as a two-shift operation). The nominal one-shift loading also accommodates surge and mobilization requirements by increasing manloading. The availability of manpower in requisite numbers and skill levels, the existence of other plant loading, such as other systems produced at the same cost center, and the capability of the industrial base including suppliers and vendors are other factors to be considered.

It may be expedient to produce some subsystems or equipments such as those common to a number of systems, at a high or premium rate to achieve an efficient output on the entire system. Conversely, some systems are intrinsically of so high unit cost as to preclude establishing an efficient rate for many component items.

An economical production profile for the FYDP makes use of programed facilization and rate tooling augmentations which are to increase capacity in the outyears. The planned economical rate employs programed increases in plant capacity that are cost beneficial, i.e., incremental facilization costs result in substantial return on investment. The economical production rate and procurement profile for the planned inventory quantity should be determined no later than the start of engineering development.

APPENDIX B

PRODUCTION RATE REVIEW

APRO PROJECT 84-05

DETERMINING ECONOMIC PRODUCTION RATES

PRODUCTION RATE REVIEW

PRODUCTION RATE REVIEW (PRR)

A FORMAL ASSESSMENT OF INDUSTRIAL BASE CAPABILITIES. ADDRESSES THE ABILITY OF THE INDUSTRIAL BASE TO PROVIDE COST EFFECTIVE ARMY MILITARY SYSTEMS. IS CONDUCTED: AFTER FULL SCALE DEVELOPMENT, WITH CONTRACTOR AND GOVERNMENT PARTICIPATION, EMPLOYING AN INTERVIEW DISCUSSION METHODOLOGY, AT THE CONTRACTOR'S FACILITIES.

PURPOSE

TO DETERMINE THE MINIMUM SUSTAINING, MINIMUM EFFICIENT, MAXIMUM EFFICIENT, AND MAXIMUM PRODUCTION RATES SUCH THAT PER-UNIT-COST AND STATEMENT OF READINESS STATISTICS CAN BE COMPUTED AND REPORTED AS REQUIRED BY PROGRAM OBJECTIVE MEMORANDUM AND ARMY MATERIEL PLAN GUIDANCE.

PLANNING SCHEDULE

REVIEW DIRECTOR SELECTED

MEMBERSHIP SELECTED AND
  PROVIDED PLAN OUTLINE

TEAM MEETING

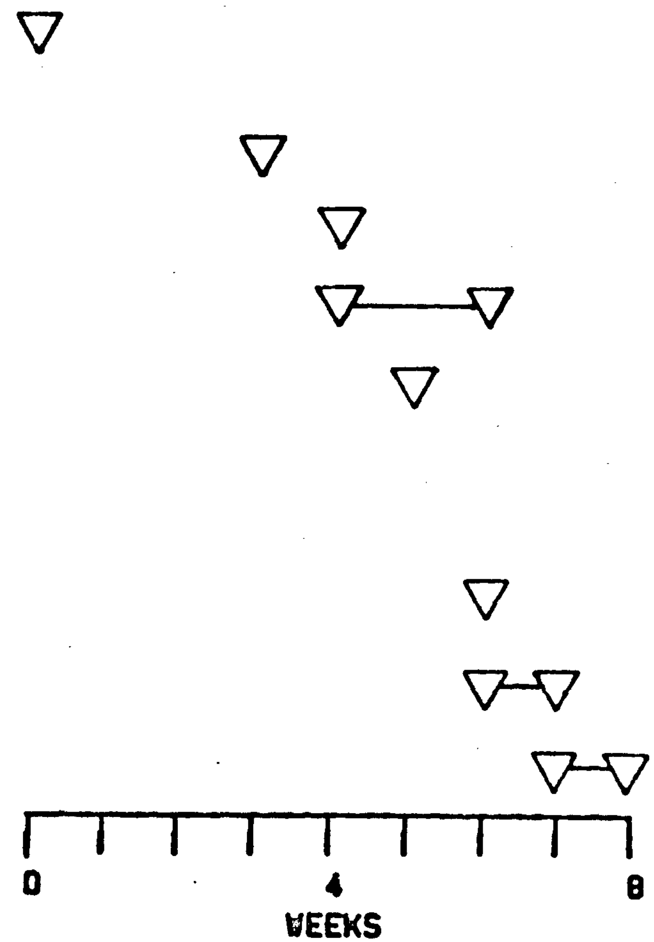
PREPARE INTERVIEW QUESTIONS

REQUEST CONTRACTOR PARTICIPATION
  PROVIDE: PLAN OUTLINE
           TEAM MEMBERSHIP
           EXECUTION DATE

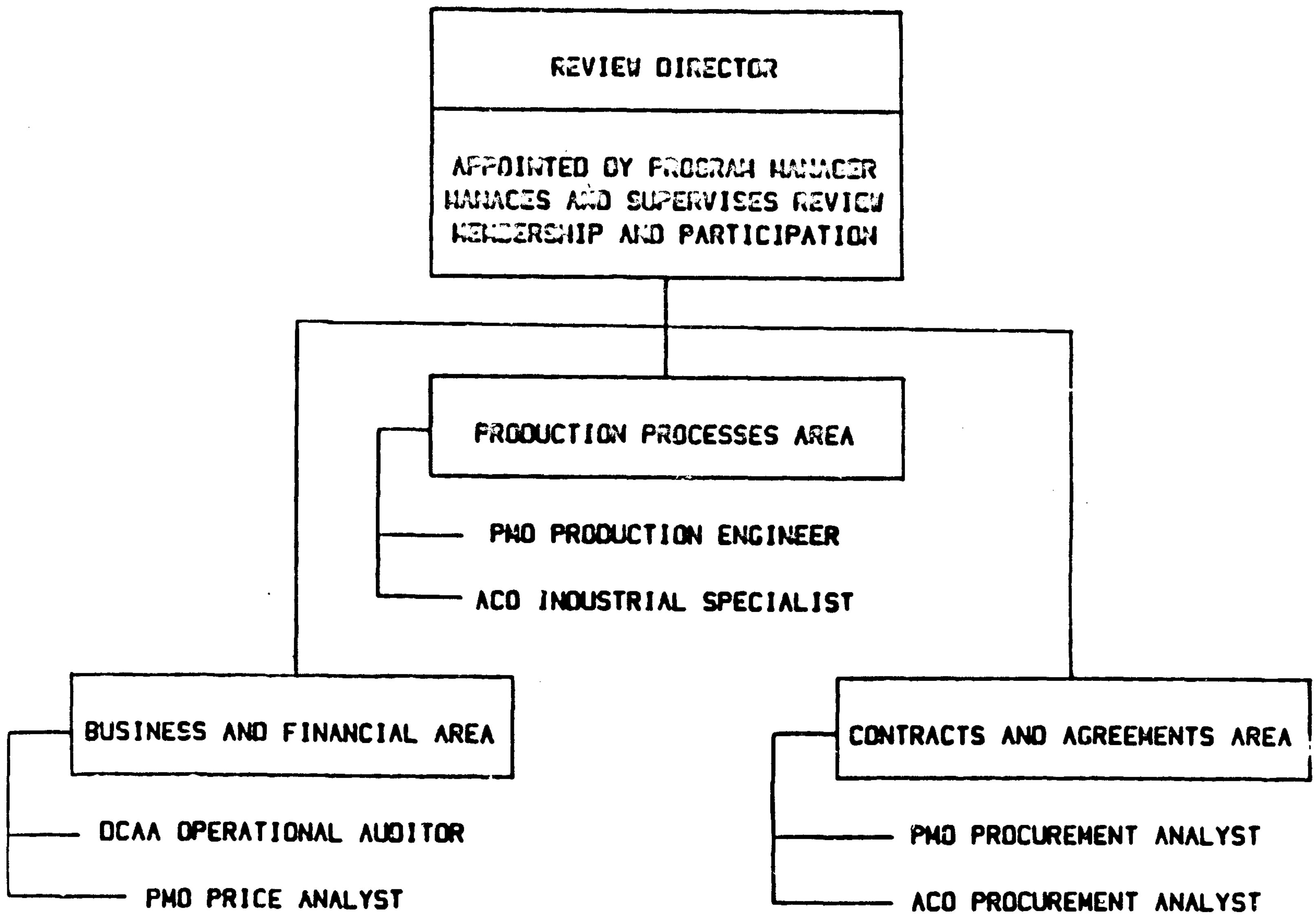
TEAM MEETING

CONDUCT PRR

CONSOLIDATE RESULTS



ORGANIZATION AND MEMBERSHIP



CONTRACTS AND AGREEMENTS AREA

EXAMINE PURCHASING, SUBCONTRACTING, AND INDUSTRIAL RELATIONS FUNCTIONS TO ASCERTAIN THE POTENTIAL IMPACT OF OPERATING AT DIFFERENT PRODUCTION RATES. AS A MINIMUM INVESTIGATE FUNCTIONS FOR:

1. STANDARD ITEMS
   - A. EOQ'S
   - B. LEADTIMES
   - C. DISCOUNTS
   - D. MULT'SOURCING
2. PRODUCTS
   - A. VOLUME
   - B. QUANITTY DEPENDENCE
   - C. DURATION
   - D. OTHER
3. LABOR
   - A. TURN-OVER
   - B. SHIFT/OVERTIME
   - C. SKILL AVAILABILITY
   - D. UNION CONSTRAINTS

PRODUCTION PROCESSES AREA

EXAMINE MANUFACTURING, FABRICATION, ASSEMBLY, INSPECTION, ACCEPTANCE TESTING, AND SHIPPING FUNCTIONS TO ASCERTAIN THE POTENTIAL ALTERATIONS NECESSARY TO ACHIEVE EACH PRODUCTION RATE. AS A MINIMUM, INVESTIGATE EACH FUNCTION FOR:

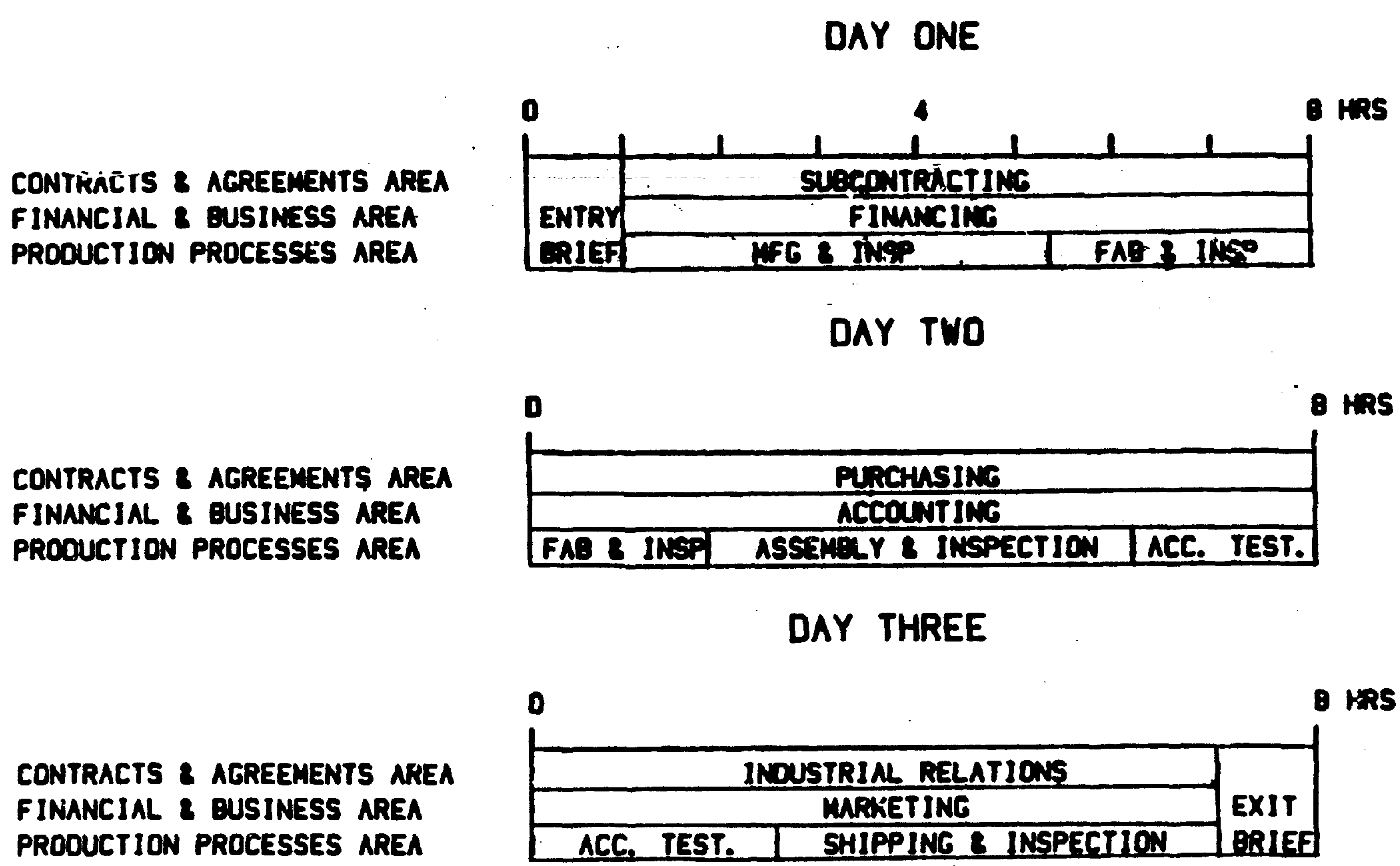
1. FACILITIES
   - A. LOCATION
   - B. SPACE
   - C. EQUIPMENT
   - D. CONTROLLING FACTORS
2. WORK LOAD
   - A. SCHEDULING
   - B. TEMPORARY STORAGE
   - C. MATERIALS
   - D. CONTROLLING FACTORS
3. WORK FORCE
   - A. SIZE VARIATIONS
   - B. TIME STANDARDS
   - C. WORKING HOURS
   - D. EFFICIENCIES

FINANCIAL AND BUSINESS AREA

EXAMINE FINANCE, MARKETING, AND ACCOUNTING FUNCTIONS TO ASCERTAIN THE POTENTIAL IMPACT OF OPERATING AT DIFFERENT PRODUCTION RATES. AS A MINIMUM, INVESTIGATE EACH FUNCTION FOR:

1. COMPETING SALES
   - A. COMMERCIAL
   - B. GOVERNMENT
   - C. FMS
   - D. OTHER
2. OPERATING EXPENSES
   - A. MATERIALS
   - B. LABOR
   - C. OVERHEAD
   - D. PROFIT
3. ADVANCED PLANNING
   - A. INDUSTRY ANALYSIS
   - B. CASH FLOW STRATEGIES
   - C. BUDGETING
   - D. OTHER

EXECUTION SCHEDULE



APPENDIX C

TASK ORDER STATEMENTS OF WORK

1. With Cost Factors
2. Without Cost Factors

STATEMENT OF WORK

CONTENTS

1.0. **SUMMARY.** The Project Office, with collaboration from the Army Procurement Research Office, is investigating the cost sensitivity of manufacturing missiles at different production rates. To accomplish this investigation, five predetermined delivery schedules (see paragraph 3.0) have been constructed to serve as the standard for collecting the desired cost data. Each schedule has been partitioned into six discrete purchases. Each hypothetical purchase will be made twenty-one months before the first delivery. To assure no production breaks, the second purchase will be made eleven months after the first, and each of the four remaining purchases will be sequentially made at twelve month intervals. From these predetermined delivery schedules, the contractor shall prepare cost estimates for each purchase in terms of the present business environment. The contractor shall also analyze each purchase, rearrange the distribution of missiles into a least cost delivery schedule, and prepare corresponding cost estimates. The Project Office and the Army Procurement Research Office shall analyze the results to assist in the preparation of budgets, justifications, and special studies. The results shall not be used for source selection.

2.0. **TASKING.** This effort shall have three general tasks. Task One involves developing cost estimates for a set of five predetermined delivery schedule Task Two involves the definition of a set of five least cost delivery schedules for a specific quantity of missiles. Task Three is the development of the cost estimates resulting from the least cost delivery schedules defined in Task Two.

2.1.1. **TASK ONE.** The contractor shall develop cost estimates for manufacturing all-up-round missiles at production rates established by the five predetermined delivery schedules in paragraph 3.0. The contractor shall develop cost estimates for each of the six purchases of each predetermined delivery schedule in paragraph 3.0. Each cost estimate shall have six factors: direct labor (less overtime), overtime, material (less subcontracting and inventory), subcontracting, inventory (or holding), and overhead.

2.1.2. Quantities scheduled for delivery in a particular month shall be considered as accepted F.O.B. at the point of origin on the last working day of the month. All cost estimate factors shall be specified in discounted constant year (March, 1985) dollars at a ten per cent rate. The sum of the six factors shall equal the total cost of each purchase.

2.1.3. The contractor shall document and report the six cost factors for each purchase of each predetermined delivery schedule. The documenting format shall be determined by the contractor, but a clear relationship shall be maintained between the six factors, each purchase, and each predetermined delivery schedule.

2.2.1. TASK TWO. The contractor shall analyze the monthly delivery quantities of each purchase of each predetermined delivery schedule in paragraph 3.0. The contractor shall increase or decrease the quantity of missiles scheduled for delivery during a particular month to define a set of least cost delivery schedules.

2.2.2. Quantities scheduled for delivery in a particular month shall be considered as accepted F.O.B. at the point of origin on the last working day of the month. Each least cost delivery schedule shall be partitioned into six purchases corresponding to the six purchases of the predetermined delivery schedules in paragraph 3.0. The first purchase of each least cost delivery schedules shall be considered a transition purchase from the current contractual production rate to a new level of production. The fourth purchase of the "Cut-Back" least cost delivery schedule shall be considered a transition purchase from the twelve missile per day average production rate of purchase three (and two), to the production rate of purchase five (and six). The quantity for the "Total Buy" least cost delivery schedule shall not exceed 28,800 missiles. The quantity for the "75%" least cost delivery schedule shall not exceed 22,300 missiles. The quantity for the "Cut-Back" least cost delivery schedule shall not exceed 16,200 missiles. The quantity for the "25%" least cost delivery schedule shall not exceed 9,400 missiles. The quantity for the "Minimum" least cost delivery schedule shall not exceed 4,300 missiles. The number of months in a purchase shall not be increased or decreased, and the chronology shall not be altered.

2.2.3. The contractor shall also develop the least cost "award" leadtime (the length of time, in months, from a purchase to the delivery of the first lot) for each of the six purchases of each of the five least cost delivery schedules.

2.2.4. The contractor shall document and report a least cost "award" leadtime and monthly delivery quantities for each purchase of each of the five least cost delivery schedules. The documenting format shall be determined by the contractor; however, a clear relationship betweem leadtime, month, year, quantity, purchase, and schedule title shall be maintained.

2.3.1. TASK THREE. The contractor shall develop cost estimates for producing the five least cost delivery schedules defined in paragraph 2.2.1. The contractor shall prepare cost estimates for each purchase of each least cost delivery schedule defined in paragraph 2.2.1. Each cost estimate shall have six factors: direct labor (less overtime), overtime, material (less subcontracting and inventory), subcontracting, inventory (or holding), and overhead.

2.3.2. Quantities scheduled for delivery in a particular month shall be considered as accepted F.O.B. at the point of origin on the last working day of the month. All cost estimate factors shall be specified in discounted constant year (March, 1985) dollars at a ten per cent rate. The sum of the six factors shall

equal the total cost of each purchase of each least cost delivery schedule.

2.3.3. The contractor shall document and report six cost factors for each purchase of each least cost delivery schedule defined in paragraph 2.2.1. The documenting format shall be determined by the contractor, but a clear relationship between each purchase of each least cost delivery schedule and the six factors shall be maintained.

3.0. **PREDETERMINED DELIVERY SCHEDULES.** There are five predetermined delivery schedules which have been entitled: Total Buy, 75%, Cut-Back, 25% and Minimum. Each predetermined delivery schedule has been partitioned into six purchases. Each purchase is representative of a "contract award" and has an award leadtime of twenty-one months.

3.1. **PURCHASE ONE.** Awarded Feburary, 1985.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
DEC 86	246	239	235	225	220
JAN 87	314	297	237	264	251
FEB 87	309	285	270	238	219
MAR 87	351	316	294	247	219
APR 87	345	304	278	221	188
MAY 87	339	292	261	177	159
JUN 87	384	323	284	202	153
JUL 87	395	326	281	187	132
AUG 87	388	313	265	164	105
SEP 87	398	315	262	150	84
OCT 87	428	333	272	142	66
SUM	3897	3343	2989	2217	1796

3.2. **PURCHASE TWO.** Awarded March, 1986.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 87	379	289	232	109	38
DEC 87	339	259	207	98	38
JAN 88	399	305	244	115	40
FEB 88	419	320	256	121	42
MAR 88	459	350	281	133	46
APR 88	399	305	244	115	40
MAY 88	419	320	256	121	42
JUN 88	439	335	268	127	44
JUL 88	399	305	244	115	40
AUG 88	459	350	281	133	46
SEP 88	419	320	256	121	42
OCT 88	419	320	256	121	42
SUM	4948	3778	3025	1429	496

3.3. PURCHASE THREE. Awarded March, 1987.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 88	413	305	252	133	42
DEC 88	413	320	252	78	30
JAN 89	413	320	252	139	44
FEB 89	413	289	252	98	38
MAR 89	413	350	252	152	48
APR 89	413	305	252	93	36
MAY 89	413	335	252	146	46
JUN 89	413	335	252	108	42
JUL 89	413	305	252	133	42
AUG 89	413	350	252	113	44
SEP 89	413	305	252	133	42
OCT 89	413	230	252	108	42
SUM	4956	3749	3024	1434	496

3.4. PURCHASE FOUR. Awarded March, 1988.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 89	399	320	239	119	46
DEC 89	399	217	176	119	26
JAN 90	439	352	252	119	51
FEB 90	379	289	324	119	34
MAR 90	439	352	241	119	51
APR 90	419	289	214	119	34
MAY 90	439	352	230	119	51
JUN 90	419	304	215	119	36
JUL 90	419	336	210	119	48
AUG 90	459	333	224	119	39
SEP 90	379	304	180	119	44
OCT 90	439	333	213	119	39
SUM	5028	3781	2618	1428	499

3.5. PURCHASE FIVE. Awarded March, 1989.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 90	419	350	180	115	41
DEC 90	284	194	135	115	41
JAN 91	461	385	198	127	41
FEB 91	379	259	180	109	41
MAR 91	440	368	189	121	41
APR 91	398	272	189	127	41
MAY 91	461	385	198	127	41
JUN 91	379	259	180	115	41
JUL 91	461	385	198	127	41
AUG 91	417	285	198	127	41
SEP 91	419	350	180	115	41
OCT 91	436	298	207	127	41
SUM	4554	3790	2232	1452	492

3.6. **PURCHASE SIX.** Awarded March, 1990.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 91	436	315	186	115	38
DEC 91	271	315	186	88	42
JAN 92	505	315	186	133	44
FEB 92	339	315	186	109	38
MAR 92	505	315	186	133	44
APR 92	356	315	186	115	44
MAY 92	459	315	186	121	40
JUN 92	373	315	186	120	44
JUL 92	505	315	186	133	44
AUG 92	356	315	186	115	42
SEP 92	462	315	186	127	42
OCT 92	373	315	186	120	42
SUM	4960	3780	2232	1429	504

STATEMENT OF WORK

CONTENTS

1.0. SUMMARY. The Project Office, with collaboration from the Army Procurement Research Office, is investigating the cost sensitivity of manufacturing missiles at different production rates. To accomplish this investigation, five predetermined delivery schedules (see paragraph 3.0) have been constructed to serve as the standard for collecting the desired cost data. Each schedule has been partitioned into six discrete purchases. Each hypothetical purchase will be made twenty-one months before the first delivery. To assure no production breaks, the second purchase will be made eleven months after the first, and each of the four remaining purchases will be sequentially made at twelve month intervals. From these predetermined delivery schedules, the contractor shall prepare cost estimates for each purchase in terms of the present business environment. The contractor shall also analyze each purchase, rearrange the distribution of missiles into a least cost delivery schedule, and prepare corresponding cost estimates. The Project Office and the Army Procurement Research Office shall analyze the results to assist in the preparation of budgets, justifications, and special studies. The results shall not be used for source selection.

2.0. TASKING. This effort shall have three general tasks. Task One involves developing cost estimates for a set of five predetermined delivery schedules. Task Two involves the definition of a set of five least cost delivery schedules for a specific quantity of missiles. Task Three is the development of the cost estimates resulting from the least cost delivery schedules defined in Task Two.

2.1.1. TASK ONE. The contractor shall develop cost estimates for manufacturing all-up-round missiles at production rates established by the five predetermined delivery schedules in paragraph 3.0. The contractor shall develop cost estimates for each of the six purchases of each predetermined delivery schedule in paragraph 3.0. 2.1.2. Quantities scheduled for delivery in a particular month shall be considered as accepted F.O.B. at the point of origin on the last working day of the month. All cost estimates shall be specified in discounted constant year (March, 1985) dollars at a ten per cent rate.

2.1.3. The contractor shall document and report the six cost estimates for each predetermined delivery schedule in paragraph 3.0. The documenting format shall be determined by the contractor, but a clear relationship between each predetermined delivery schedule and the six cost estimates shall be maintained.

2.2.1. TASK TWO. The contractor shall analyze the monthly delivery quantities of each purchase of each predetermined delivery schedule in paragraph 3.0. The contractor shall increase or decrease the quantity of missiles scheduled for delivery during a particular month to define a set of least cost delivery schedules.

2.2.2. Quantities scheduled for delivery in a particular month shall be considered as accepted F.O.B. at the point of origin on the last working day of the month. Each least cost delivery schedule shall be partitioned into six purchases corresponding to the six purchases of the predetermined delivery schedules in paragraph 3.0. The first purchase of each least cost delivery schedules shall be considered a transition purchase from the current contractual production rate to a new level of production. The fourth purchase of the "Cut-Back" least cost delivery schedule shall be considered a transition purchase from the twelve missile per day average production rate of purchase three (and two), to the production rate of purchase five (and six). The quantity for the "Total Buy" least cost delivery schedule shall not exceed 28,800 missiles. The quantity for the "75%" least cost delivery schedule shall not exceed 22,300 missiles. The quantity for the "Cut-Back" least cost delivery schedule shall not exceed 16,200 missiles. The quantity for the "25%" least cost delivery schedule shall not exceed 9,400 missiles. The quantity for the "Minimum" least cost delivery schedule shall not exceed 4,300 missiles. The number of months in a purchase shall not be increased or decreased, and the chronology shall not be altered.

2.2.3. The contractor shall also develop the least cost "award" leadtime (the length of time, in months, from a purchase to the delivery of the first lot) for each of the six purchases of each of the five least cost delivery schedules.

2.2.4. The contractor shall document and report a least cost "award" leadtime and monthly delivery quantities for each purchase of the five least cost delivery schedules. The documenting format shall be determined by the contractor; however, a clear relationship betweem leadtime, month, year, quantity, purchase, and schedule title shall be maintained.

2.3.1. TASK THREE. The contractor shall develop cost estimates for producing the five least cost delivery schedules defined in paragraph 2.2.1. The contractor shall prepare cost estimates for each purchase of each least cost delivery schedule defined in paragraph 2.2.1.

2.3.2. Quantities scheduled for delivery in a particular month shall be considered as accepted F.O.B. at the point of origin on the last working day of the month. All cost estimates shall be specified in discounted constant year (March, 1985) dollars at a ten per cent rate.

2.3.3. The contractor shall document and report six cost estimates for each least cost delivery schedule defined in paragraph 2.2.1. The documenting format shall be determined by the contractor, but a clear relationship between each cost estimate, purchase and each least cost delivery schedule shall be maintained.

3.0. PREDETERMINED DELIVERY SCHEDULES. There are five predeter-

mined delivery schedules which have been entitled: Total Buy, 75%, Cut-Back, 25% and Minimum. Each predetermined delivery schedule has been partitioned into six purchases. Each purchase is representative of a "contract award" and has an award leadtime of twenty-one months.

3.1. PURCHASE ONE. Awarded Feburary, 1985.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
DEC 86	246	239	235	225	220
JAN 87	314	297	287	264	251
FEB 87	309	285	270	238	219
MAR 87	351	316	294	247	219
APR 87	345	304	278	221	188
MAY 87	339	292	261	177	159
JUN 87	384	323	284	202	153
JUL 87	395	326	281	187	132
AUG 87	388	313	265	164	105
SEP 87	398	315	262	150	84
OCT 87	428	333	272	142	66
SUM	3897	3343	2989	2217	1796

3.2. PURCHASE TWO. Awarded March, 1986.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 87	379	289	232	109	38
DEC 87	339	259	207	98	38
JAN 88	399	305	244	115	40
FEB 88	419	320	256	121	42
MAR 88	459	350	281	133	46
APR 88	399	305	244	115	40
MAY 88	419	320	256	121	42
JUN 88	439	335	268	127	44
JUL 88	399	305	244	115	40
AUG 88	459	350	281	133	46
SEP 88	419	320	256	121	42
OCT 88	419	320	256	121	42
SUM	4948	3778	3025	1429	496

3.3. **PURCHASE THREE.** Awarded March, 1987.

DELIVERIES

BOUND TARGET DATE	SCHEDULE QUANTITIES TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 88	413	305	252	133	42
DEC 88	413	320	252	78	30
JAN 89	413	320	252	139	44
FEB 89	413	289	252	98	38
MAR 89	413	350	252	152	48
APR 89	413	305	252	93	36
MAY 89	413	335	252	146	46
JUN 89	413	335	252	108	42
JUL 89	413	305	252	133	42
AUG 89	413	350	252	113	44
SEP 89	413	305	252	133	42
OCT 89	413	230	252	108	42
SUM	4956	3749	3024	1434	496

3.4. **PURCHASE FOUR.** Awarded March, 1988.

DELIVERIES

BOUND TARGET DATE	SCHEDULE QUANTITIES TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 89	399	320	239	119	46
DEC 89	399	217	176	119	26
JAN 90	439	352	252	119	51
FEB 90	379	289	324	119	34
MAR 90	439	352	241	119	51
APR 90	419	289	214	119	34
MAY 90	439	352	230	119	51
JUN 90	419	304	215	119	36
JUL 90	419	336	210	119	48
AUG 90	459	333	224	119	39
SEP 90	379	304	180	119	44
OCT 90	439	333	213	119	39
SUM	5028	3781	2618	1428	499

3.5. PURCHASE FIVE. Awarded March, 1989.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 90	419	350	180	115	41
DEC 90	284	194	135	115	41
JAN 91	461	385	198	127	41
FEB 91	379	259	180	109	41
MAR 91	440	368	189	121	41
APR 91	398	272	189	127	41
MAY 91	461	385	198	127	41
JUN 91	379	259	180	115	41
JUL 91	461	385	198	127	41
AUG 91	417	285	198	127	41
SEP 91	419	350	180	115	41
OCT 91	436	298	207	127	41
SUM	4554	3790	2232	1452	492

3.6. PURCHASE SIX. Awarded March, 1990.

DELIVERIES

BOUND	SCHEDULE QUANTITIES				
TARGET DATE	TOTAL BUY	75 PER CENT	CUT-BACK	25 PER CENT	MIN-IMUM
NOV 91	436	315	186	115	38
DEC 91	271	315	186	88	42
JAN 92	505	315	186	133	44
FEB 92	339	315	186	109	38
MAR 92	505	315	186	133	44
APR 92	356	315	186	115	44
MAY 92	459	315	185	121	40
JUN 92	373	315	186	120	44
JUL 92	505	315	186	133	44
AUG 92	356	315	186	115	42
SEP 92	482	315	186	127	42
OCT 92	373	315	186	120	42
SUM	4960	3780	2232	1429	504

APPENDIX D

DELIVERY QUANTITY DERIVATION

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INTRODUCTION.

The formulation and solution of a delivery schedule involves answering some very basic questions, fitting those answers to a specific producer, and working out the detail delivery quantities. These three procedures are described here as Defining Parameters, Establishing Work-Days, and Determining the Delivery Schedule. Within each procedure is a general solution which outlines the assumptions and derivation of the analytical equations, and an illustrative example to demonstrate the practical application. A method for determining initial production delivery quantities is also provided.

D.1. Defining Parameters. The first step in developing a plan to conduct a major system acquisition, is to investigate and define two general parameters. How many items are to be purchased, and at what time should they be purchased. With the determination of the purchase quantity, different contracting events must be carefully qualified and designated.

D.1.1. General Solution.

D.1.1.1. Determine N, the total number of units to be purchased during the life of the project.

D.1.1.2. Establish t_a, a target month and year for award of the first production contract.

D.1.1.3. Set t_b, a target month and year for delivery of the first initial production lot.

D.1.1.4. Select t_c, a target month and year for delivery of the last initial production lot.

D.1.1.5. Choose t_d, a target month and year for delivery of the last production lot.

D.1.1.6. Summarizing the results: N units are to be bought and delivered during t_a through t_d. Production deliveries will begin at t_b, and initial production will end with delivery of the lot at t_c. Figure D-1 shows the time based position of the defined contract events.

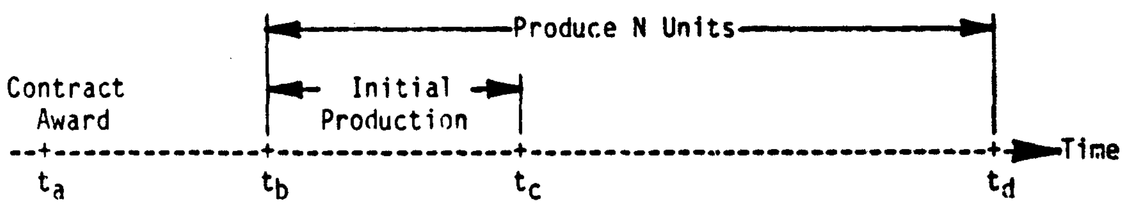

Figure D-1: Project Execution Time Line

D.1.2. Illustrative Example.

D.1.2.1 Following discussion with the potential tester, potential user, and other missile project office officials; and, totaling their anticipated requirements, the total number of missiles to purchase is set at 40,000.

D.1.2.2. Considering the present missile's technology maturity, how well full scale development testing has been going, and the expected time necessary to prepare and negotiate a sole source contract, establish a target contract award date of November 1985.

D.1.2.3. Judging the leadtimes of various materials and electronic components, and contractor discussions of integration time periods, set the last contractor work-day of July in 1987 as the delivery date for the first initial production lot.

D.1.2.4. Since most initial production periods for other missile systems have varied from ten to thirty-two months, and this missile has high

congressional attention, select the last contractor work-day in November of 1988 as the delivery date of the last initial production lot.

D.1.2.5. Checking with other missile project offices reveals that production rates vary from 150 to 1800 units per month. Subtracting 20% of the total buy for initial production, and dividing the remainder by 800 missiles per month, yields an approximate 40 month steady-state production period after initial production. Therefore, set the last contractor work-day in March of 1992 as the delivery day for the last production lot.

D.1.2.6. Summarizing in terms of Figure D-1:

$$N = 40{,}000 \text{ missiles}$$

$$t_a = \text{Nov } 85$$

$$t_b = \text{Jul } 87$$

$$t_c = \text{Nov } 88$$

$$t_d = \text{Mar } 92$$

D.2. Establishing Work-Days. With the determination of the total number of units to be purchased and target dates for significant events, the establishment of a contractor's work-day schedule is necessary to control the production rate and set monthly delivery quantities. To control the production rate from t_b (Jul 87) through t_d (Nov 92), contractor holidays and scheduled shut-down periods must be deducted from the non-weekend days for each month.

D.2.1. General Solution.

D.2.1.1. Contact the sole source contractor and determine the holidays (h_i) and scheduled shut-down periods (s_i) from t_b through t_d. Also, determine if it is the contractor's policy that if a holiday occurs on a weekend it is observed on the nearest non-weekend day.

D.2.1.2. Using the data collected from the contractor (in paragraph D.2.1.1) and Table D-2, construct a contractor project workday schedule (see Table D-1). Where $W_i = l_i - (w_i + h_i + s_i)$ for i ranging from b through d.

Table D-1: Contractor Project Work-Day Schedule

month, i	b	b+1	...	c-1	c	c+1	...	d-1	d
calendar days, l_i	l_b	l_{b+1}		l_{c-1}	l_c	l_{c+1}		l_{d-1}	l_d
weekend days, w_i	w_b	w_{b+1}		w_{c-1}	w_c	w_{c+1}		w_{d-1}	w_d
holidays, h_i	h_b	h_{b+1}		h_{c-1}	h_c	h_{c+1}		h_{d-1}	h_d
shut-down days, s_i	s_b	s_{b+1}		s_{c-1}	s_c	s_{c+1}		s_{d-1}	s_d
work-days, W_i	W_b	W_{b+1}	...	W_{c-1}	W_c	W_{c+1}	...	W_{d-1}	W_d

D.2.2. Illustration Example.

D.2.2.1. The following holidays and shut-down periods were secured from the contractor:

a. New Year's Day (1 January)

b. Good Friday (third Friday in April)

c. Memorial Day (28 May)

d. Labor Day (3 September)

e. Independence Day (4 July)

f. Thanksgiving Day

g. day after Thanksgiving Day

h. Christmas Eve (24 December)

i. Christmas Day (25 December)

j. New Year's Eve (31 December)

k. Two week shut down period (last full week in July plus all or a part week in August

l. Holidays occurring on weekend days are observed on the nearest non-weekend day

D.2.2.2. From Table D-2 construct a workday schedule (Table D-3). From Table D-2 locate the desired year and month, sum the non-weekend (Wk) and weekend (wi) days and record it in the calendar days square of Table D-3. Observe the weekend days (wi) in Table D-2 and record that value in the corresponding square of Table D-3. Distribute the holidays and shut-down periods into the appropriate squares of Table D-3. Sum the shut-downs, holidays and weekend days, subtract that sum from the calendar days, and enter the resulting workdays in the appropriate month of Table D-3.

TABLE D-2· MONTHLY Wk AND wi FOR A 280 YEAR PERIOD

YEAR: 1952, 1980, 2008, 2036, 2064, 2092, 2120, 2148, 2176, 2204

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Tu	Fr	Sa	Tu	Th	Su	Tu	Fr	Mo	We	Sa	Mo
wk	23	21	21	22	22	21	23	21	22	23	20	23
wi:	8	8	10	8	9	9	8	10	8	8	10	8

YEAR: 1953, 1981, 2009, 2037, 2065, 2093, 2121, 2149, 2177, 2205

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Th	Su	Su	We	Fr	Mo	We	Sa	Tu	Th	Su	Tu
wk:	22	20	22	22	21	22	23	21	22	22	21	23
wi:	9	8	9	8	10	8	8	10	8	9	9	8

YEAR: 1954, 1982, 2010, 2038, 2066, 2094, 2122, 2150, 2178, 2206

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Fr	Mo	Mo	Th	Sa	Tu	Th	Su	We	Fr	Mo	We
wk:	21	20	23	22	21	22	22	22	22	21	22	23
wi:	10	8	8	8	10	8	9	9	8	10	8	8

YEAR: 1955, 1983, 2011, 2039, 2067, 2095, 2123, 2151, 2179, 2207

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Sa	Tu	Tu	Fr	Su	We	Fr	Mo	Th	Sa	Tu	Th
wk:	21	20	23	21	22	22	21	23	22	21	22	22
wi:	10	8	8	9	9	8	10	8	8	10	8	9

YEAR: 1956, 1984, 2012, 2040, 2068, 2096, 2124, 2152, 2180, 2208

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Su	We	Th	Su	Tu	Fr	Su	We	Sa	Mo	Th	Sa
wk:	22	21	22	21	23	21	22	23	20	23	22	21
wi:	9	8	9	9	8	9	9	8	10	8	8	10

YEAR: 1957, 1985, 2013, 2041, 2069, 2097, 2125, 2153, 2181, 2209

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Tu	Fr	Fr	Mo	We	Sa	Mo	Th	Su	Tu	Fr	Su
wk:	23	20	21	22	23	20	23	22	21	23	21	22
wi:	8	8	10	8	8	10	8	9	9	8	9	9

YEAR: 1958, 1986, 2014, 2042, 2070, 2098, 2126, 2154, 2182, 2210

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	We	Sa	Sa	Tu	Th	Su	Tu	Fr	Mo	We	Sa	Mo
wk:	23	20	21	22	22	21	23	21	22	23	20	23
wi:	8	8	10	8	9	9	8	10	8	8	10	8

YEAR: 1959, 1987, 2015, 2043, 2071, 2099, 2127, 2155, 2183, 2211

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Th	Su	Su	We	Fr	Mo	We	Sa	Tu	Th	Su	Tu
wk:	22	20	22	22	21	22	23	21	22	22	21	23
wi:	9	8	9	8	10	8	8	10	8	9	9	8

NOTE: Wk = Non-Weekend days, and wi = Weekend days

TABLE D-2: MONTHLY Wk AND wi FOR A 280 YEAR PERIOD (Cont'd)

YEAR: 1960, 1988, 2016, 2044, 2072, 2100, 2128, 2156, 2184, 2212

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Fr	Mo	Tu	Fr	Su	We	Fr	Mo	Th	Sa	Tu	Th
Wk:	21	21	23	21	22	22	21	23	22	21	22	22
wi:	10	8	8	9	9	8	10	8	8	10	8	9

YEAR: 1961, 1989, 2017, 2045, 2073, 2101, 2129, 2157, 2185, 2213

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Su	We	We	Sa	Mo	Th	Sa	Tu	Fr	Su	We	Fr
Wk:	22	20	23	20	23	22	21	23	21	22	22	21
wi:	9	8	8	10	8	8	10	8	9	9	8	10

YEAR: 1962, 1990, 2018, 2046, 2074, 2102, 2130, 2158, 2186, 2214

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Mo	Th	Th	Su	Tu	Fr	Su	We	Sa	Mo	Th	Sa
Wk:	23	20	22	21	23	21	22	23	20	23	22	21
wi:	8	8	9	9	8	9	9	8	10	8	8	10

YEAR: 1963, 1991, 2019, 2047, 2075, 2103, 2131, 2159, 2187, 2215

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Tu	Fr	Fr	Mo	We	Sa	Mo	Th	Su	Tu	Fr	Su
Wk:	23	20	21	22	23	20	23	22	21	23	21	22
wi:	8	8	10	8	8	10	8	9	9	8	9	9

YEAR: 1964, 1992, 2020, 2048, 2076, 2104, 2132, 2160, 2188, 2216

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	We	Sa	Su	We	Fr	Mo	We	Sa	Tu	Th	Su	Tu
Wk:	23	20	22	22	21	22	23	21	22	22	21	23
wi:	8	9	9	8	10	8	8	10	8	9	9	8

YEAR: 1965, 1993, 2021, 2049, 2077, 2105, 2133, 2161, 2189, 2217

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Fr	Mo	Mo	Th	Sa	Tu	Th	Su	We	Fr	Mo	We
Wk:	21	20	23	22	21	22	22	22	22	21	22	23
wi:	10	8	8	8	10	8	9	9	8	10	8	8

YEAR: 1966, 1994, 2022, 2050, 2078, 2106, 2134, 2162, 2190, 2218

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Sa	Tu	Tu	Fr	Su	We	Fr	Mo	Th	Sa	Tu	Th
wk:	21	20	23	21	22	22	21	23	22	21	22	22
wi:	10	8	8	9	9	8	10	8	8	10	8	9

YEAR: 1967, 1995, 2023, 2051, 2079, 2107, 2135, 2163, 2191, 2219

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Su	We	We	Sa	Mo	Th	Sa	Tu	Fr	Su	We	Fr
Wk:	22	20	23	20	23	22	21	23	21	22	22	21
wi:	9	8	8	10	8	8	10	8	9	9	8	10

NOTE: Wk = Non-Weekend days, and wi = Weekend days

TABLE D-2: MONTHLY WK AND wi FOR A 280 YEAR PERIOD (Cont'd)

YEAR: 1968, 1996, 2024, 2052, 2080, 2108, 2136, 2164, 2192, 2220

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Mo	Th	Fr	Mo	We	Sa	Mo	Th	Su	Tu	Fr	Su
Wk:	23	21	21	22	23	20	23	22	21	23	21	22
wi:	8	8	10	8	8	10	8	9	9	8	9	9

YEAR: 1969, 1997, 2025, 2053, 2081, 2109, 2137, 2165, 2193, 2221

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	We	Sa	Sa	Tu	Th	Su	Tu	Fr	Mo	We	Sa	Mo
Wk:	23	20	21	22	22	21	23	21	22	23	20	23
wi:	8	8	10	8	9	9	8	10	8	8	10	8

YEAR: 1970, 1998, 2026, 2054, 2082, 2110, 2138, 2166, 2194, 2222

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Th	Su	Su	We	Fr	Mo	We	Sa	Tu	Th	Su	Tu
Wk:	22	20	22	22	21	22	23	21	22	22	21	23
wi:	9	8	9	8	10	8	8	10	8	9	9	8

YEAR: 1971, 1999, 2027, 2055, 2083, 2111, 2139, 2167, 2195, 2223

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Fr	Mo	Mo	Th	Sa	Tu	Th	Su	We	Fr	Mo	We
Wk:	21	20	23	22	21	22	22	22	22	21	22	23
wi:	10	8	8	8	10	8	9	9	8	10	8	8

YEAR: 1972, 2000, 2028, 2056, 2084, 2112, 2140, 2168, 2196, 2224

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Sa	Tu	We	Sa	Mo	Th	Sa	Tu	Fr	Su	We	Fr
Wk:	21	21	23	20	23	22	21	23	21	22	22	21
wi:	10	8	8	10	8	8	10	8	9	9	8	10

YEAR: 1973, 2001, 2029, 2057, 2085, 2113, 2041, 2169, 2197, 2225

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Mo	Th	Th	Su	Tu	Fr	Su	We	Sa	Mo	Th	Sa
Wk:	23	20	22	21	23	21	22	23	20	23	22	21
wi:	8	8	9	9	8	9	9	8	10	8	8	10

YEAR: 1974, 2002, 2030, 2058, 2086, 2114, 2142, 2170, 2198, 2226

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	Tu	Fr	Fr	Mo	We	Sa	Mo	Th	Su	Tu	Fr	Su
Wk:	23	20	21	22	23	20	23	22	21	23	21	22
wi:	8	8	10	8	8	10	8	9	9	8	9	9

YEAR: 1975, 2003, 2031, 2059, 2087, 2115, 2143, 2171, 2199, 2227

MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1st:	We	Sa	Sa	Tu	Th	Su	Tu	Fr	Mo	We	Sa	Mo
Wk:	23	20	21	22	22	21	23	21	22	23	20	23
wi:	8	8	10	8	9	9	8	10	8	8	10	8

NOTE: Wk = Non-Weekend days, and wi = Weekend days

TABLE D-2: MONTHLY WK AND wi FOR A 280 YEAR PERIOD (Cont'd)

YEAR: 1976, 2004, 2032, 2060, 2088, 2116, 2144, 2172, 2200, 2228

*MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC *
*1st:	Th	Su	Mo	Th	Sa	Tu	Th	Su	We	Fr	Mo	We *
*Wk:	22	20	23	22	21	22	22	22	22	21	22	23 *
*wi:	9	9	8	8	10	8	9	9	8	10	8	8 *

YEAR: 1977, 2005, 2033, 2061, 2089, 2117, 2145, 2173, 2201, 2229

*MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC *
*1st:	Sa	Tu	Tu	Fr	Su	We	Fr	Mo	Th	Sa	Tu	Th *
*Wk:	21	20	23	21	22	22	21	23	22	21	22	22 *
*wi:	10	8	8	9	9	8	10	8	8	10	8	9 *

YEAR: 1978, 2006, 2034, 2062, 2090, 2118, 2146, 2174, 2202, 2230

*MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC *
*1st:	Su	We	We	Sa	Mo	Th	Sa	Tu	Fr	Su	We	Fr *
*Wk:	22	20	23	20	23	22	21	23	21	22	22	21 *
*wi:	9	8	8	10	8	8	10	8	9	9	8	10 *

YEAR: 1979, 2007, 2035, 2063, 2091, 2119, 2147, 2175, 2203, 2231

*MON:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC *
*1st:	Mo	Th	Th	Su	Tu	Fr	Su	We	Sa	Mo	Th	Sa *
*Wk:	23	20	22	21	23	21	22	23	20	23	22	21 *
*wi:	8	8	9	9	8	9	9	8	10	8	8	10 *

NOTE: Wk = Non-Weekend days, and wi = Weekend days

Table D-3: Work-Day Schedule

Month	7-87	8-87	9-87	10-87	11-87	12-87	1-88	2-88	3-88	4-88	5-88	6-88	7-88	8-88	9-88
Calendar days	31	31	30	31	30	31	31	29	31	30	31	30	31	31	30
Weekend days	8	10	8	9	9	8	10	8	8	9	9	8	10	8	8
Holidays	1	0	1	0	2	3	1	0	0	1	1	0	1	0	1
Shut-downs	5	5	0	0	0	0	0	0	0	0	0	0	5	5	0
Work-days	17	16	21	22	19	20	20	21	23	20	21	22	15	18	21

Month	10-88	11-88	12-88	1-89	2-89	3-89	4-89	5-89	6-89	7-89	8-89	9-89	10-89	11-89	12-89
Calendar Days	31	30	31	31	28	31	30	31	30	31	31	30	31	30	31
Weekend Days	10	8	9	9	3	8	10	8	8	10	8	9	9	8	10
Holidays	0	2	3	1	0	0	1	1	0	1	0	1	0	2	3
Shut-downs	0	0	0	0	0	0	0	0	0	6	4	0	0	0	0
Work-days	21	20	19	21	20	23	19	22	22	14	19	20	22	20	18

Month	1-90	2-90	3-90	4-90	5-90	6-90	7-90	8-90	9-90	10-90	11-90	12-90	1-91	2-91	3-91
Calendar Days	31	28	31	30	31	30	31	31	30	31	30	31	31	28	31
Weekend Days	8	8	9	9	8	9	9	8	10	8	8	10	8	8	10
Holidays	0	0	0	1	1	0	1	0	1	0	2	3	1	0	0
Shut-downs	0	0	0	0	0	0	7	3	0	0	0	0	0	0	0
Work-days	23	20	22	20	22	21	14	20	19	23	20	18	22	20	21

Month	4-91	5-91	6-91	7-91	8-91	9-91	10-91	11-91	12-91	1-92	2-92	3-92
Calendar Days	30	31	30	31	31	30	31	30	31	31	29	31
Weekend Days	8	8	10	8	9	9	8	9	9	8	9	9
Holidays	1	1	0	1	0	1	0	2	3	1	0	0
Shut-downs	0	0	0	8	2	0	0	0	0	0	0	0
Work-days	21	22	20	14	20	20	23	19	19	22	20	22

D.3. Setting The Delivery Schedule. The final objective is to develop a delivery schedule which exhibits a production rate similar to that in Figure D-2. That is, the production rate increases at a linear rate and

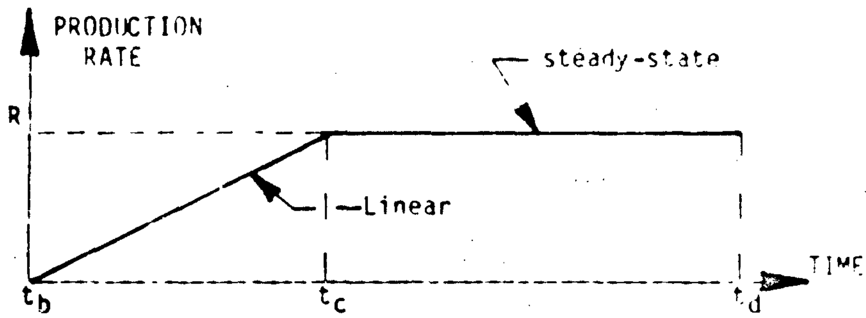

Figure D-2: Ideal Production Rate

levels off at a constant economic production rate (R). From the calculations of W_i in Table D-1, it can be observed that delivery quantities per month will only be constant if the work-days per month are constant.

D.3.1 General Solution.

D.3.1.1 Since the production rate is the number of units produced divided by the time consumed in their production, the product of the production rate and time equals units. And, the sum of units produced during initial and steady-state production must equal the total number of units to be produced. Therefore, with reference to Figure D-2:

$$N - 0.5R\,[t_c - t_b] + R\,[t_d - t_{c+1}], \text{ but}$$

$$[t_c - t_b] = \sum_{i=b}^{c} W_i$$ (which is the number of work-days in initial production) and

$$[t_d - t_{c+1}] = \sum_{i=c+1}^{d} W_i$$ (which is the number of work-days in steady-state production). Hence,

$$N = 0.5R \sum_{i=b}^{c} W_i + R \sum_{i=c+1}^{d} W_i, \text{ and}$$

$$R = \frac{N}{0.5 \sum_{i=b}^{c} W_i + \sum_{i=c+1}^{d} W_i}. \qquad (1)$$

Equation (1) states that the (steady-state) economic production rate (R) equals the total purchase quantity divided by the sum of one-half the work-days in initial production and the work-days after initial production.

D.3.1.2. To compute the changing production rates for initial production, consider the linear behavior of production rate in Figure D-3. Assuming that no finished units have been produced before month b, and rate increases linearly from zero to R during initial production. Then the average daily

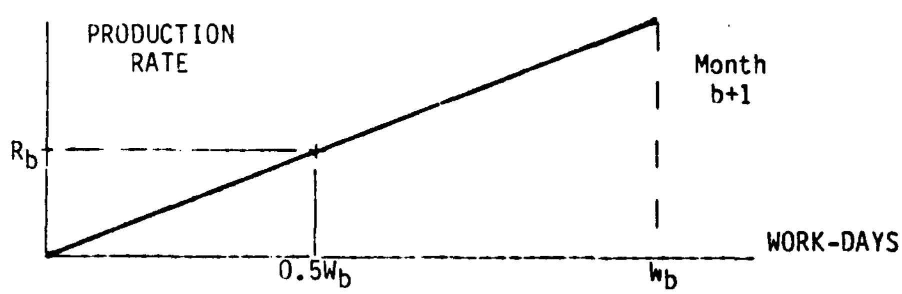

Figure D-3: Average Daily Production Rate for Month b.

production rates for months b (Figure D-2) through c are determined by:

$$R_b = \frac{0.5W_b}{\sum_{i=b}^{c} W_i} R,$$

$$R_{b+1} = \frac{0.5W_{b+1} + W_b}{\sum_{i=b}^{c} W_i} R,$$

$$R_{b+2} = \frac{0.5W_{b+2} + W_{b+1} + W_b}{\sum_{i=b}^{c} W_i} R,$$

$$R_{b+3} = \frac{0.5W_{b+3} + W_{b+2} + W_{b+1} + W_b}{\sum_{i=b}^{c} W_i} R,$$

$$\vdots$$

$$R_{c-1} = \frac{0.5W_{c-1} + \sum_{i=b}^{c-2} W_i}{\sum_{i=b}^{c} W_i} R, \text{ and}$$

$$R_c = \frac{0.5W_c + \sum_{i=b}^{c-1} W_i}{\sum_{i=b}^{c} W_i} R.$$

From these solutions for production rate, the delivery quantities for each month of initial production can be determined.

D.3.2. Illustrative Example.

D.3.2.1. Combining the results of paragraph D.1.2.6. and Table D-3 with equation (1) provide the steady-state production rate:

$$\sum_{i=b}^{c} W_i = 17 + 16 + 21 + 22 + 19 + 20 + 20 + 21 + 23 + 20 + 21 + 22 + 15 + 18 + 21 + 21 + 20$$

$$= 337 \text{ work-days}$$

$$\sum_{i=c+1}^{d} W_i = 19 + 21 + 20 + 23 + 19 + 22 + 22 + 14 + 19 + 20 + 22 + 20 + 18 + 23 + 22 + 22 + 20 + 22 + 21 + 14 + 20 + 19 + 23 + 20 + 18 + 22 + 20 + 21 + 21 + 22 + 20 + 14 + 20 + 20 + 23 + 19 + 19 + 22 + 20 + 22$$

$$= 808 \text{ work-days}$$

$$N = 40{,}000 \text{ units}$$

$$R = \frac{40{,}000}{0.5\,(337) + 808} = 40.9626 \ \frac{\text{units}}{\text{work-day}}$$

D.3.2.2. For the initial production period:

$$R_b = \frac{0.5(17)}{337} R = 1.0332 \ \frac{\text{units}}{\text{work day}}$$

$$R_{b+1} = \frac{0.5(16) + 17}{337} R = 3.0388 \ \frac{\text{units}}{\text{work-day}}$$

$$R_{b+2} = \frac{0.5(21) + 16 + 17}{337} R = 5.2875 \ \frac{\text{units}}{\text{work-day}}$$

$$\vdots$$

$$R_{c-1} = \frac{0.5(21) + 296}{337} R = 37.2553 \ \frac{\text{units}}{\text{work-day}}$$

$$R_c = \frac{0.5(20) + 317}{337} R = 39.7471 \ \frac{\text{units}}{\text{work-day}}$$

From these calculations, the monthly delivery quantities (q_i) can be determined as shown in Table D-4. By carefully adding the monthly

Table D-4: Monthly Delivery Quantities

Month	7-87	8-87	9-87	10-87	11-87	12-87	1-88	2-88	3-88	4-88
Quantity	18	49	111	174	197	255	304	371	468	459
Month	5-88	6-88	7-88	8-88	9-88	10-88	11-88	12-88	1-89	2-89
Quantity	535	618	455	582	729	782	795	778	860	819
Month	3-89	4-89	5-89	6-89	7-89	8-89	9-89	10-89	11-89	12-89
Quantity	942	778	901	901	573	778	819	901	819	737
Month	1-90	2-90	3-90	4-90	5-90	6-90	7-90	8-90	9-90	10-90
Quantity	942	901	901	819	901	860	573	819	778	942
Month	11-90	12-90	1-91	2-91	3-91	4-91	5-91	6-91	7-91	8-91
Quantity	819	737	901	819	860	860	901	819	573	819
Month	9-91	10-91	11-91	12-91	1-92	2-92	3-92			
Quantity	819	942	778	778	901	819	901			

deliveries of Table D-4, a total of 39,990 missiles have been scheduled for delivery. The ten missile difference (40,000 - 39,990) is the result of round-off error. The round-off error may be reduced by evenly distributing the ten missiles over the delivery schedule. To determine where to place the ten missiles, an analysis must be made to establish where the error occurred (initial or steady-state production). Adding the delivery quantities for initial production (July 87 through November 88) yields 6,902 missiles. Then using part of the equation (1) which defined R:

$$0.5R\,[t_c - t_b] = 0.5R \sum_{i=b}^{c} W_i$$

$$= 0.5\ (40.9626)\ (337)$$

$$= 6{,}902 \text{ missiles.}$$

Adding the delivery quantities for steady-state production yields 33,088 missiles. Then using the other part of the equation which defined R:

$$R\,[t_d - t_{c+1}] = R \sum_{i=c+1}^{d} W_i$$

$$= 40.9626\ (808)$$

$$= 33{,}098 \text{ missiles}$$

Therefore, the round-off error occurred in steady-state production.

To determine where (in steady-state production) the ten missiles should be placed requires an analysis of: the number of workdays (W_i), their frequency (f_i), and a comparison of actual production rate (r_i), and steady-state production rate as shown in Table D-5.

Table D-5: Production Rate Analysis

f_i	q_i	W_i	r_i	$R-r_i$	$\frac{q_i + 1}{W_i}$
3	573	14	40.9286	0.0341	41.0
2	737	18	40.9444	0.0182	41.0
6	778	19	40.9474	0.0153	41.0
11	819	20	40.95	0.0126	41.0
4	860	21	40.9524	0.0102	41.0
10	901	22	40.9545	0.0081	41.0
4	942	23	40.9565	0.0061	41.0

Table D-5 indicates that if the delivery quantity for any month is increased by one missile, the production rate increases to 41 missiles per work-day. However, to increase the delivery quantity of each month by one missile would require 40 missiles (the sum of f_i) and only ten are available. Therefore, because there are ten months having 22 work-days, select those months to have 902 missiles delivered (note: consideration was given to placing the missiles such that the change in variation from R was minimized, but the solution would yield months with the same number of work-days having different delivery quantities).

Because of the deterministic nature of the previous derivation, the programming and operation of this methodology on a "personal" size computer would appear to be the next logical step. Also, there could be an application for the "learning" curve function when computing initial production delivery quantities. Preliminary analysis indicates that round-off error could be corrected through use of the "learning" curve function.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER APRO 84-05	2. GOVT ACCESSION NO. AD-A159 733	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Determining Economic Production Rates		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Tracy Worthington		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of the Deputy Chief of Staff for Logistics ATTN: DALO-PRO Fort Lee, VA 23801-6045		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Army Materiel Command ATTN: AMCPP-IP 5001 Eisenhower Avenue, Alexandria, VA 22333		12. REPORT DATE August 1985
		13. NUMBER OF PAGES 91
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Procurement
Production Planning
Demand Analysis
Scheduling
Economic Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Present definitions fall short of describing the true nature of various production rates. Alternative definitions are proposed and optional procedures for determining various production rates are described. The procedures include theoretical models, data items, production rate reviews, task order contracting, and elective scheduling. Present scheduling techniques build in large variations in production rates which could impact unit cost. Where circumstances permit, it is recommended that bid and proposal preparation instructions specify the total delivery quantity, the months in which deliveries are to be made, and a request for the offeror to

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propose a least cost delivery schedule.